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Integrated Technical Information for the Air Logistics Centers (ITI-ALC)
Phase II Final Report

Joyce M. Mansheim
Ron Sutton

Lockheed Martin
Information Systems
12506 Lake Underhill Road
Orlando, FL 32825-5002

Laurie Quill

University of Dayton Research Institute
Human Factors Group
300 College Park
Dayton, OH 45469

Paul Faas
Barbara L. Masquelier
Cheryl L. Batchelor
Robert Hartz
Patrick Pohle
Steve Grace

Air Force Research Laboratory

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Mark M. Hoffman

MARK M. HOFFMAN
Deputy Chief
Deployment and Sustainment Division
Air Force Research Laboratory

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Joyce M. Mansheim, Ron Sutton, Laurie Quill, Paul Faas, Barbara L. Masquelier,
Cheryl L. Batchelor, Robert Hartz, Patrick Pohle, Steve Grace

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Lockheed Martin
Information Systems
12506 Lake Underhill Road
Orlando, FL 32825-5002

University of Dayton Research Institute
Human Factors Center
300 College Park
Dayton, OH 45469

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13. ABSTRACT *(Maximum 200 words)*

The objective of the Integrated Technical Information for the Air Logistics Center (ITI-ALC) research is to improve the effectiveness and efficiency of depot aircraft maintenance by designing, developing, and demonstrating technology to improve, standardize, integrate, and make more accessible at the job, maintenance technical and management information. This document summarizes the activities and results of the ITI-ALC Phase II Research and Development program. Information is presented on the user-centered development process, the prototypes prepared, the personnel involved, and the facility resources that supported this research and development effort. A description is provided of the design and development of the following proof-of-concept prototype tools: Engineering Assistance/Collaboration prototype tool and Evaluation and Inventory Inspection prototype tool. Information is also presented on the training administered to participants for prototype evaluation, the instruments and methods used to collect user feedback, the user feedback data collected, and the resulting conclusions and recommendations based on this user feedback.

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Preface

The ITI-ALC Phase II effort was sponsored by the United States Air Force Research Laboratory (AFRL), Human Effectiveness Directorate (HESR), Wright Patterson Air Force Base, Dayton, Ohio. Continuity and understanding of the work done for ITI-ALC Phase I was facilitated by the presence of the same Laboratory personnel for both phases of the ITI-ALC effort. (Phase I work was completed by Systems Research and Applications Corporation (SRA) in 1995, and generated several key documents used as inputs to ITI-ALC Phase II including: SSI, etc.).

Laboratory personnel participated actively in all major activities of the Phase II project. They reviewed early prototype designs, arranged logistics, observed user and contractor behavior during site visits, and served as data collectors during the field-based evaluation activities. Individuals who represented AFRL/HESR included: Captain Bob Hartz, Lt. Patrick Pohle, Lt. Steven Grace, Ms. Barbara Masquelier, Dr. Donald Thomas, Ms. Cheryl Batchelor, and Mr. Paul Faas.

The ITI-ALC Phase II effort began with Lockheed Martin Information Systems (LMIS), Orlando, Florida as the Prime Contractor assisted by three subcontractors: Battelle, Carnegie Mellon University, and Lockheed Martin Advanced Technology Laboratory (LM ATL). As the project progressed, the statement of work and resources available were modified and both Battelle and LM ATL completed their involvement with the effort.

Acknowledgements

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1.1 Introduction

Phase II of the ITI-ALC program utilized an iterative, user-centered development approach to identify the PDM processes currently in use, propose technologies that could be affordably used to automate those processes, and implement prototype applications to evaluate those proposals. This approach provided the program's subjects (PDM mechanics) with periodic opportunities to review and guide the development effort in directions that best fit the environment and processes that they live with on a daily basis. The team's frequent visits and interactions with the subjects kept them interested and involved throughout the twenty months of Phase II.

Ten PDM personnel participated in FBE #1 in June 1997. Nine of the ten had no prior computer experience. They inspected and tried out a variety of advanced hardware and software, witnessed a demonstration and discussed with the ITI-ALC team how these devices and techniques could help them spend more time working on aircraft. Based on the results of these discussions, we developed a plan to demonstrate and evaluate tools that automated, to various degrees, the following PDM processes:

- Aircraft Evaluation and Inventory (E&I)
- Engineering Assistance Request (202 Form)
- Electronic Identification and Signoff
- Electronic Technical Order (TO) Delivery
- Operations Check
- PDM Planning and Scheduling
- PDM/Backshop Schedule Coordination
- Backshop Routing and Tracking

As the program progressed, the initial thirty-six month period of performance was reduced to twenty months due to funding cuts. While the initial goal of the program was to evaluate quantitatively the impact of the introduction of automation to the PDM line, the reduced period of performance made it impossible to directly measure this. The largest impacts were a by-product of electronic dissemination of information, as opposed to a reduction in the time required to perform the tasks being automated. It would have required the ITI-ALC tools to have been fielded for several weeks in order to make measurements of these impacts. Since this was no longer possible, we developed revised goals that focused on user interface usability and constraints on implementation of a system similar to ITI-ALC in the PDM environment.

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1.2 ITI-ALC Tools

The final ITI-ALC tools included an E&I application, an Engineering Assistance Request (202 Form) application, electronic Technical Order delivery system that was integrated with these applications, and an electronic identification/signoff system that was also integrated with the two applications. The E&I application guided inspectors through required inspection tasks and allowed them to record defects and task completion. The 202 Form application helped mechanics complete the 202 form, filling in fields for them or providing pull-downs when possible. It allowed mechanics to record and attach digital voice notes and/or user-annotated digital photographs to the 202 form prior to submission. The integrated TO delivery system allowed mechanics to view IPDF versions of F-15E technical data from within either application, and the electronic identification (ID) system was used for logging on to either application and signing off of tasks in the E&I application. The two applications were hosted on a mobile computer (a Fujitsu Stylistic 1200) which could be worn by the mechanics during use.

The 1200s were equipped with customized versions of Commercial Off-The-Shelf (COTS) cases that allowed the user to 'wear' them using a strap through which the user's neck and one arm were inserted. A 'comfort pad' was added to the lower edge of the cases to provide space between the user's abdomen and the screen and to support the 1200 in a position perpendicular to the user's body. The iButton reader used for electronic ID/signoff was mounted just above the right side of the display, and a ViCam digital camera was attached to the right-hand side of the case. The pen used for input was tethered to a ring on the right (for right-handed users) or left (for left-handed users) side of the case (see Fujitsu 1200 in case with accessories in Figure 1.2-1).
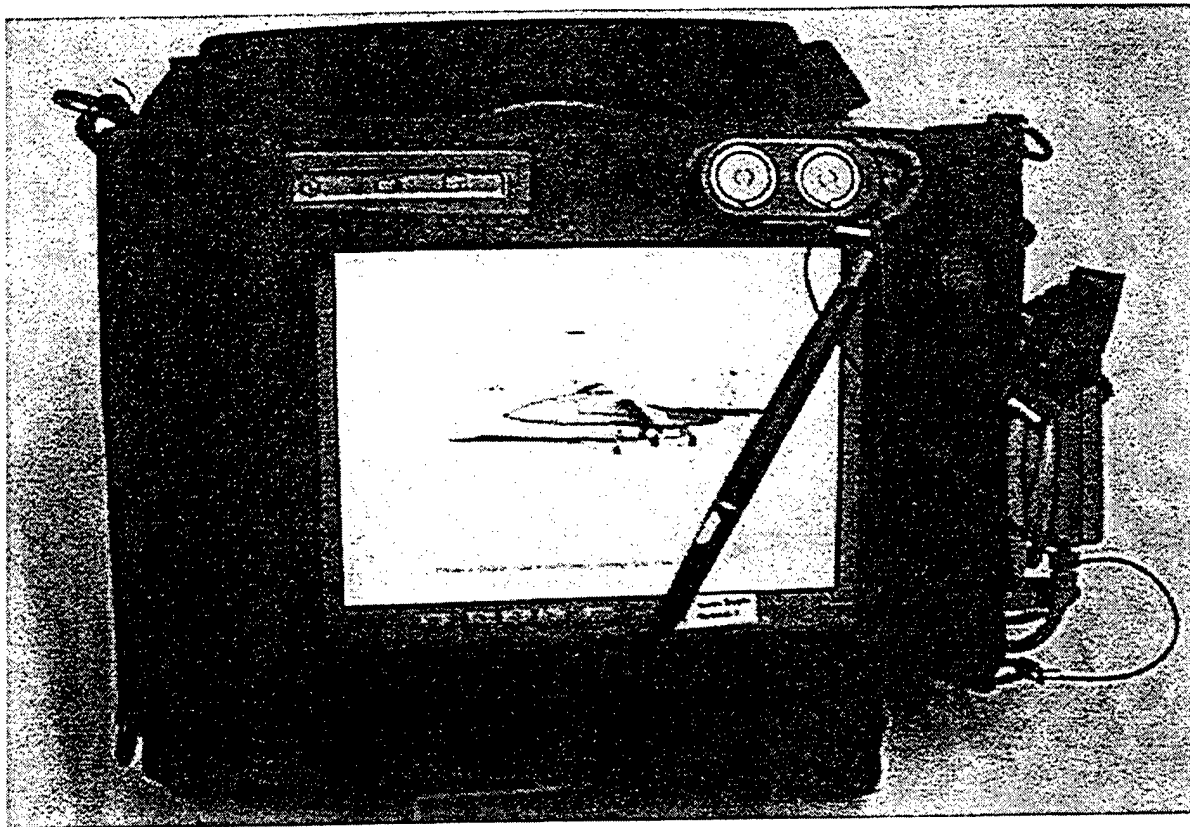
Figure 1.2-1 Fujitsu Stylistic 1200 with modified case

1.3 Field Test Methodology

There were eleven final field test/Field Based Evaluation #3 (FBE #3) participants. Three of these were E&I inspectors, six were sheet metal mechanics, and two were engineers. Data collection methodologies included use of questionnaires, evaluator observations, subject interviews, and in some cases, a paper walk-through of the applications. Each subject evaluated only the ITI-ALC application that was consistent with his major job skill; i.e., E&I inspectors evaluated only the E&I application, sheet metal mechanics evaluated the mechanic's portions of the Engineering Assistance Request application and engineers evaluated the engineer's portions of the Engineering Assistance Request application. All mechanics evaluated the electronic technical orders and electronic identification implementation. Subjects received training that varied in length from one to two hours, depending upon the speed with which each subject mastered the material, with two subjects being trained at a time in most cases. After demonstrating a minimum level of proficiency with the application, mechanics were allowed to use the mobile systems on which the applications were hosted to complete at least two tasks each. Very little assistance was provided to the mechanics during their use of the systems. Engineers performed a tabletop discussion with evaluators in lieu of actual use due to their very different experience base.

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1.4 Field Test Results

The mechanics reported that the ITI-ALC tools provided them with "increased access to information", and felt that novices could easily use the tools with experience. They reported that they would use the tools frequently, and that they would use them in the performance of their primary job. They noted several specific areas in which the tools would be helpful, including:

- performance of depot maintenance on aircraft
- part number lookup
- guiding repairs
- search for general information
- fast, secure electronic 173 card signoffs
- faster and easier parts ordering
- increased access to technical data
- aiding mechanics in performing tasks outside their specialty

Participants also noted several areas in which the tools require improvement. They noted that the mobile system would not be useful in tight areas (mechanics can barely squeeze into some confined areas of the F-15E without the mobile computer). It is reasonable to expect that users might perform inspections and/or repair work, then record results off-aircraft.

Mechanics suggested that the screen used to select electronic technical orders (TOs) be reorganized to display available TOs according to (1) aircraft location, (2) technician specialty and/or (3) numeric sequence. The tools currently display them in either alphabetical order by TO title or by TO category (e.g., Job Guides, Illustrated Parts Breakdowns, et cetera). While most of the rest of the GUI seemed to be adequate, inspectors seemed to have difficulty remembering to tap the "+" icon on the 'Add Defects' screen in order to record the just-entered defect.

The human/computer interface exhibited other 'rough' areas. Users input information to the Fujitsu 1200 by writing and 'tapping' with a pen on the display (tapping replaces the mouse button clicking used on a desktop computer). Almost every user had difficulty 'tapping' icons with the mobile's pen. A very particular 'tapping method' must be used before taps would be recognized. Engineering analysis showed that this was a problem with Internet Explorer 4.0, rather than the Fujitsu 1200. The same screens worked flawlessly with Internet Explorer 3.x, and with Netscape 4.x. Unfortunately, this was perceived by many users as a computer problem.

Similarly, once a 'tap' <u>was</u> recognized by the 1200, on some screens the cursor would flicker between the normal 'pointer' cursor and a 'wait' cursor for several seconds. This

would be followed by a delay of up to several seconds before any action could be seen. During this time, the user was unsure if the tap had registered or not. Engineering analysis showed that this, too, was peculiar to Internet Explorer. The cursor flickered once for every hidden field on the screen (sometimes over 100 times).

The mobile computers themselves proved to be adequate for the task for which they were selected, although some users expressed concern about the ruggedness of the 1200s, saying that they worried about breaking them during field test use. Their 120-megahertz (MHz) clock speed provided reasonable responsiveness for the thin client implementation. The (relatively expensive) Thin-Film Transistor (TFT) active matrix display performed well in the harsh lighting of the aircraft hangar. The applications were implemented as HTML pages, which were served on demand to the 1200s via a wireless LAN. The wireless LAN had a peak advertised throughput of 1.6 megabits per second, which proved to be adequate for small numbers of concurrent users; tests with larger numbers of users were not conducted. The wireless LAN exhibited some sensitivity to use in close proximity (within 3 to 6 feet) to operating microwave ovens, particularly when receiving data.

Electronic signoffs used a small metal button ("iButton") to identify mechanics; the button was mounted in an angled plastic holder that could be attached to a keychain or worn around the neck on a chain. During electronic identification operations, the user inserted the iButton into the reader mounted above the 1200's display, where spring tension held the iButton in place. While mechanics liked the speed and security of the iButton-based signoffs, they noted that the button could easily be dislodged from the reader if left in place during use of the mobile system. This is a serious concern. Aircraft are plagued by "Foreign Object Damage" (FOD), which often occurs when tools or small parts are dropped into the aircraft and not subsequently recovered. Failure to properly secure iButtons would inevitably result in FOD.

Several mechanics had problems maintaining the 1200s in an attitude suitable for viewing the screen and providing input, particularly when taking digital photos. When taking photos, the user viewed the digital camera output in a window displayed on the 1200's screen, and turned the camera lens to focus. Once the image was focused, the user held the camera still and depressed a button on top of the ViCam to 'freeze' the image. All users had difficulty focusing the camera adequately, partly because the viewing window was too small and partly because of the relatively slow refresh rate of the image. Subsequent engineering analysis showed that enlarging the screen window results in much better-focused images, even when the refresh rate is not changed. This is an important result, since the ViCam's refresh rate is inversely proportional to the quality and detail of the final image (i.e., better images can be obtained at the expense of slower refresh rates).

The users accepted the software user interface design was accepted with little comment (with the exception of certain unlabeled icons in the E&I application). Mechanics were able to learn and use the tools with relatively little training (1 to 2 hours), despite having

little or no prior computer experience. This is noteworthy, as Air Force training budgets are expected to continue to dwindle for the foreseeable future. We believe that the user interface design succeeded due to (1) minimization of the variety of widgets used in the applications, (2) the direct manner in which the user interface design related to the existing work processes, (3) the extensive use of pictorial icons, with common images incorporated into icons corresponding to related tasks and the availability of an identical navigation bar on every screen within each application.

1.5 Recommendations

While users generally felt that the ITI-ALC tools would help them to do their jobs faster and better, improvements are clearly necessary in several areas. Those can be broadly divided into two major categories: hardware issues and user interface issues. The following paragraphs discuss our findings and recommendations in these areas.

Hardware Issues
The Fujitsu Stylistic 1200s demonstrated at FBE #3 were judged to be the best fit for mobile PDM use based on the state of current technology. They offered adequate performance, particularly when used as 'thin' clients. The 1200's display was bright and clear even in direct sunlight and had a wide viewing angle, but was relatively small (8-inch diagonal) and low-resolution (640x480). The small display size resulted in increased scrolling by the user, and limited the usefulness of the device when viewing large graphics (e.g., schematics, Illustrated Parts Breakdowns). The 1200 has I/O (input/output) ports on the body of the unit, unlike many competing products that require a port expander for I/O port access. The 1200 comes with a lithium ion battery pack that provides for longer use per charge. Units could probably be used at least half a shift (of continuous use) before requiring a fresh battery. Lithium ion batteries offer a longer battery pack life (i.e., more charge/discharge cycles before battery must be discarded) than other technologies, thus reducing cost of ownership.

Some users were concerned that they would damage the unit during use. The 1200s are not ruggedized to meet military standards, but they are made for mobile use; while they would probably not survive a 10 foot drop, incidental impacts with doors, desks, etc. did not seem to damage them. None of the 1200s used on the program was damaged despite heavy travel, shipping and use on the depot floor. When selecting among otherwise acceptable computers for PDM floor use, there are two important considerations besides ruggedness to consider. The first is weight. A basic 1200 (right out of the box) weighed 3.9 pounds. Comparable (Pentium 100+MHz, TFT display) ruggedized machines weighed 5.8 to 9.6 pounds. The 1200 as configured for FBE #3 (case, ViCam, iButton reader) weighed close to 5 pounds, and the development team's subjective experience with prolonged use showed that neck and shoulder fatigue result from use longer than 30 minutes. The second consideration is cost; comparable ruggedized units cost 200+% the cost $5,000 cost of the 1200. The additional cost could be invested in spares, or reserved for future replacement of obsolete units.

As discussed above, mechanics liked the iButtons for electronic logon and 173 card signoff, but were concerned about their tendency to pop out of the reader upon relatively modest impact to the iButton holder. While not used during FBE #3, the holders have a hole for attaching to a keychain or chain worn around the neck. Since FOD and safety concerns generally discourage mechanics from wearing devices around their neck, some user-acceptable alternatives should be investigated.

While users did not complain about throughput (except when searching the IPDF TOs), the developers believe that higher-throughput RF LAN equipment would be required in a large, multi-concurrent-user environment. This requirement has been mitigated somewhat by ITI-ALC's web browser-based applications; the LAN is used only when the user moves from page to page, and this should not happen frequently in normal use. Use of desktop machines connected to a wired LAN would further reduce the demand for RF LAN bandwidth.

Summary of Hardware Recommendations
This program stressed the state of the art in mobile computing. Mechanics cannot realistically be expected to carry a device as large and heavy as a Fujitsu Stylistic 1200 with them all day, but smaller platforms are not yet capable enough to support the tasks mechanics must perform. The 1200 is also too expensive for each mechanic to have a personal mobile computer. As mobile computing becomes more widespread, the price of highly capable machines will drop. The ideal platform for PDM use would have a larger screen, lower weight, run at least one shift on a fully charged set of batteries and cost less than $500. A Windows CE-based PalmPC running a CE-compatible web browser would meet most of these criteria, but the screens of currently available models are not adequate for TO viewing. The iButton electronic signature implementation will work as-is, provided a reasonable approach to iButton stowage can be identified.

User Interface Issues
The main problems with the user interface related to the use of the pen for input. As noted above, some of these problems (tapping, cursor jitter) were traced to Internet Explorer (as opposed to the Fujitsu 1200 or the ITI-ALC software). However, handwriting recognition accuracy and ease of editing tool use were still problematic at the end of the program. Use of handwriting editing tools was the single most complex task that the mechanics had to master in order to use ITI-ALC applications. Consequently, they were trained to use the pop-up keyboard for editing. While the tools available on the keyboard were not as powerful, they were readily usable by the mechanics. Several mechanics eschewed handwriting altogether in favor of the keyboard. It may be that the only reason more did not make this choice was their lack of familiarity (and comfort) with the QWERTY pop-up keyboard).

The Fujitsu Stylistic 1200 comes bundled with Communication Intelligence Corporation's (CIC) Handwriter recognition package. The newly available CalliGrapher from ParaGraph International offers much better recognition accuracy (including recognition

of cursive, which CIC's package does not do at all) and easier to use editing tools. Unfortunately, this package was not ready in time for use at FBE #3, and cannot be fully integrated with the 1200 because no WinTab driver has been written for the 1200. The developer's experience was that CIC's software could yield >95% accuracy when used by an experienced operator; a preview version of CalliGrapher yielded similar results with no previous experience. Handwriting input should be a viable alternative in the near future.

The other major user interface issue concerns difficulty focusing the ViCam when creating an Engineering Assistance Request. Developers learned after FBE #3 that better focus could be obtained through use of a larger image display window. However, since the image is updated at a rate of about once per second, the time lag between changing focus and seeing the resulting image on the display still requires some patience and care on the part of the user. Integration of a good autofocus digital camera would result in more uniformly focused images with less user effort. Cameras of apparently adequate quality and reasonable price were just being introduced as ITI-ALC ended.

Summary of User Interface Recommendations

The use of a limited widget set and a direct mapping between the user interface implementation and tasks with which the user was familiar helped bridge the gap between the mechanics' task expertise and their lack of computer familiarity. We found that the mechanics need to be introduced to basic computer concepts significantly increased the amount of information they had to master during training. Consequently, they had great difficulty with the relatively complex FBE #2 user interface (which was similar to that of office automation tools), while enjoying more success with the simplified FBE #3 interface.

This user interface eliminated as much manual data input as possible. This was done by providing pre-filled information or user-selectable pull-downs containing a list of valid entries for a given field. Descriptive fields requiring free-form user input still pose a problem. An improved handwriting recognition package is the best solution at the current time. Today's voice recognition systems offer less accuracy than a good handwriting package in a quiet office environment; in the (sometimes very) noisy depot, they would have even more difficulty. No currently available voice recognition packages do well at both application navigation and voice dictation. Even those intended for navigation do not work well with web-based applications because of the non-static nature of the application screens.

2. ITI-ALC Phase II Introduction

2.1 Background and Purpose

The ITI-ALC Phase II research and development program continues the work performed under the ITI-ALC Phase I effort (Contract Number F41624-94-C-5021) which determined the functional requirements of an information integration capability to support Programmed Depot Maintenance (PDM) activities. The goal of this effort has been to develop and demonstrate technology, which represents a subset of the total functionality identified in the Phase I System Segment Specification (SSS). The intent of the ITI-ALC capability is to improve PDM operations by making maintenance information more accessible, fully integrated, and easy-to-use. The focus of the ITI-ALC Phase II technology has been to improve PDM activities. One of the guiding Phase II objectives has been to provide prototypes that will demonstrate the effectiveness of as many of the Phase I Business Process Improvements (BPIs) as possible. Table 2.1-1 maps the Phase I BPIs to the Phase II Prototype.

Table 2.1-1 Mapping of Phase I BPIs to Phase II Prototypes

BPI #	BPI Description	Evaluation & Inventory	Collaboration
1	Process & Terminology Coordination	X	
2	Planning Process Enhancement	X	X
3	Acquire Parts	X	
4	Data Sharing Among All Levels of Maintenance	X	
5	Production Responsibility Centers		
6	Component Parts Acquisition Policy Changes		
7	Visibility into Part Availability		
8	Electronic Signatures	X	X
9	Performance Metrics Based on Actual Data		
10	User Technical Information Presentation System	X	X
11	Pre-Planned Over and Above / Unpredictables	X	
12	Planning Responsibility Centers		
13	Automated and Integrated Technical and Diagnostics Information	X	
14	Multi-skilled Mechanics		
15	Three Shifts of Effort		

The results of the process re-engineering activities performed in Phase I have been expanded in the design and demonstration of the ITI-ALC Phase II capability. These ITI-ALC proof-of-concept demonstrations have successfully been performed at WR-ALC (WR-ALC) Air Logistic Center (ALC). These prototypes have successfully demonstrated the potential to increase

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technicians' effectiveness and efficiency, thereby significantly reducing the flow days/cost needed to complete PDM activities. These ITI-ALC Phase II proof-of-concept prototypes were implemented using an iterative user centered approach. This approach is depicted in Figure 2.1-1.
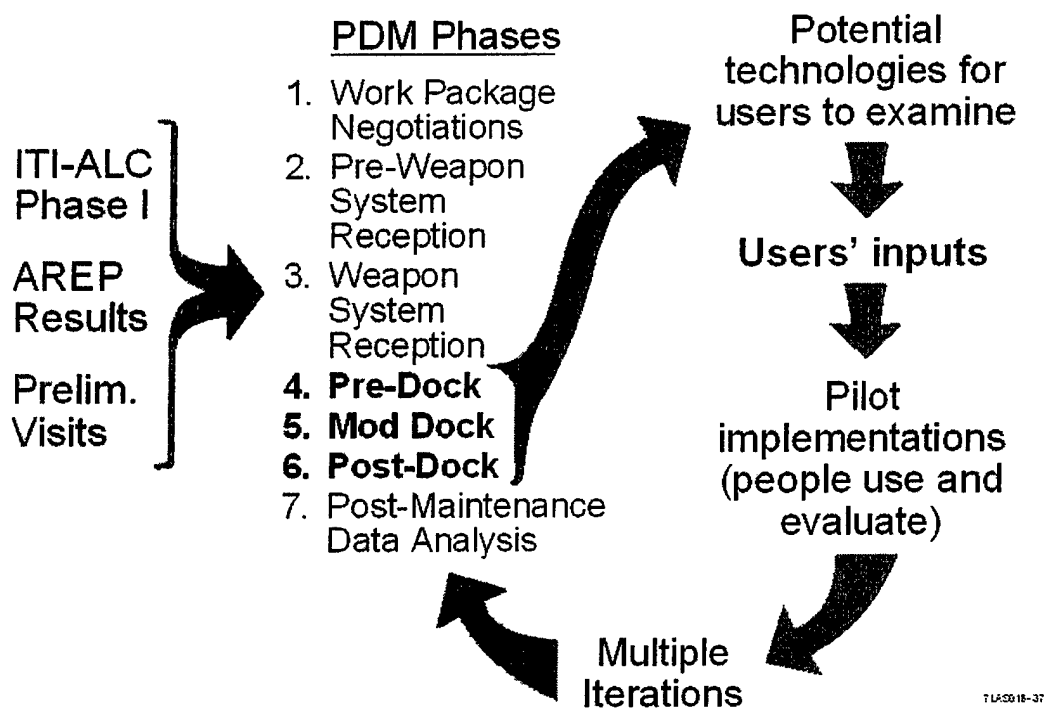
Figure 2.1-1 User Centered Program Approach

System subsets were taken to the WR-ALC for evaluation by users at multiple events. Feedback from each event was incorporated into the next prototype development iteration. Each interaction with the end users was used to obtain detailed feedback regarding the usefulness of the chosen technologies, as integrated into the demonstration prototypes. The activities and results from each event will be discussed in this document.

2.2 ITI-ALC Team Interaction

The ITI-ALC Phase II Team is comprised of the AFRL/HESR, Lockheed Martin Information Systems (LMIS), and Carnegie Mellon University (CMU). The WR-ALC AREP and F15 PDM line users have played a critical role in influencing the program direction and evaluation of the ITI-ALC prototypes. The program structure and commitment to soliciting feedback from the end user community required frequent team interactions. Figure 2.2-1 presents a flow of the work products exchanged between the team members.
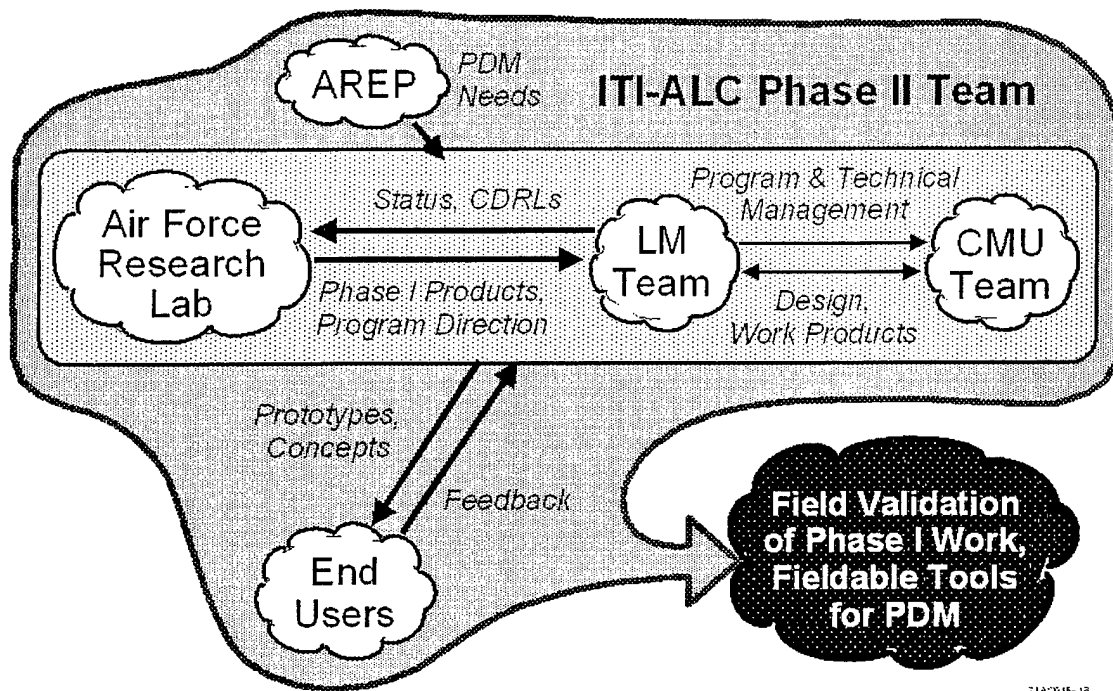
Figure 2.2-1 Team Interaction

The LMIS Demonstration and Development (DD) and Demonstration Evaluation (DE) Integrated Product Team (IPT) Leads facilitated the flow of communication and work products between the product team members, as detailed in Figure 2.2-2.
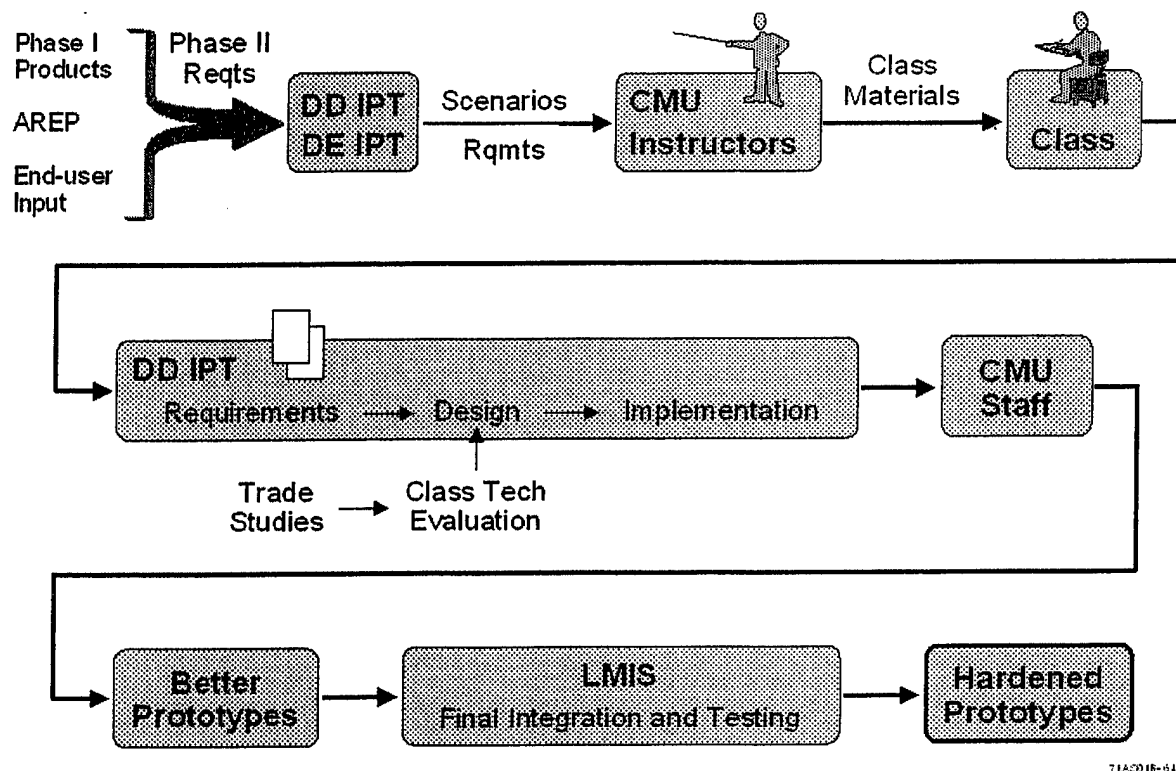
Figure 2.2-2 Team Communication Flow

2.3 Study Site and Personnel

The WR-ALC F-15 PDM line was selected as the primary site for prototype evaluation and demonstration events. The ITI-ALC program received outstanding cooperation from the WR-ALC AREP community, F-15 PDM line supervisor, and F-15 PDM line personnel (inspectors, mechanics, engineers, planners, and schedulers) to accomplish the program goals. Refer to section 3.4 for more detailed information on all study event participants.

2.4 Schedule of Study Events

There were seven primary evaluation/demonstration events conducted at WR-ALC and one data gathering event conducted at Tinker Air Force base between June 1997 and October 1998. Field-based Evaluation #1 (FBE #1) focused on informing the F-15 program about the ITI-ALC Phase II plans and promising technologies. At this event the team initiated our user-centered approach to refine and update requirements that had changed since ITI-ALC Phase I (which ended in 1995). Two data collection visits to WR-ALC and one visit to Tinker AFB followed this formal event. Each of these research field visits involved extensive interviewing and observational activities. Based on the four initial events, prototype systems to support two applications were developed at Lockheed Martin and Carnegie-Mellon University. Early versions of these prototypes were taken to Robins in November, 1997 for limited user testing and feedback about functionality, form factors of hardware, etc. All of this information was incorporated in the next iteration of the prototypes. A second FBE was held at WR-ALC in February and March 1998. This event was followed by an Air Force "shakedown" test of the prototypes in July. The final user evaluation of the two prototypes was held at Robins AFB in October 1998. A detailed description of these events is provided in Section 3 of this report.

2.5 Technician and Other Participants' Activities

The WR-ALC ALC F-15 PDM technicians have been the primary end-user focus of the ITI-ALC Phase II prototypes. Feedback on functionality and usability was also solicited from supervisors, planners, schedulers, and engineers for the applicable PDM support role that each individual performs. A user group of twenty individuals (4 inspectors, 6 skin mechanics, 2 Aircraft (A/C) mechanics, 2 A/C electrical technicians, 2 supervisors, 1 scheduler, and 1 engineer) worked with the ITI-ALC team for the duration of the project. They participated in most of the seven events mentioned in section 2.4, especially in updating the requirements, trying out prototypes over time, and providing their candid feedback to the evaluators during each prototype test. Additionally, 3 structural engineers, 2 planners, 2 AREP representatives, and 1 Non-Destructive Inspection (NDI) expert were involved in the requirements updating and in providing inputs about the prototype development as it progressed. A more detailed description of participants' activities is provided in section 3 of this document.

2.7 Organization of this Report

This document has been organized as requested by the ITI-ALC Statement of Work (SOW) to be consistent with ANSI/NISO Standard Z39.18-1995, Scientific and Technical Reports - Elements, Organization, and Design. The outline as implemented in this document is as follows:

Section 1, *ITI-ALC Phase II Summary*, summarizes the program approach, key events of the program, event results, conclusions, recommendations.

Section 2, *ITI-ALC Phase II Introduction*, provides more detail on the ITI-ALC background, purpose, study site, study personnel, study events

Section 3, *Methods and Procedures*, contains analytic information about the types of measures employed at each of the significant user interaction events.

Section 4, *Results*, contains analytic information about the types of measures employed at each of the significant user interaction events.

Section 5, *Conclusions*, summarizes the results of the significant user interaction events.

Section 6, *References*, lists document references made in this report.

Section 7, *Acronyms and Abbreviations*, spells out the acronyms and abbreviations used within this document.

The appendices of this report contain information on the Trade studies performed for this program, questionnaires, and segments of collected user feedback.

3. Methods and Procedures

The following sections describe the prototype design and development, the schedule of major study events, the maintenance tasks performed at those events (as applicable), the personnel involved in each event, and the site logistics support provided to conduct each event. The methods for participant training and the data collection procedures are also presented, as applicable.

3.1 Prototype Design & Development

The process for the design and development of the Phase II prototypes was initiated with a review of the Phase I work products identified in the ITI-ALC SOW. Multiple trips were then conducted to talk with the end users and gather feedback, as described in sections 3.2 and beyond of this document. This interaction allowed the ITI-ALC team to understand the depot environment changes initiated by the Re-engineering Office since completion of Phase I. It also allowed the ITI-ALC team to focus on those areas that targeted BPIs of particular concern and could contribute to the re-engineering effort without duplicating current initiatives. The initial Phase II software requirements were drafted as a result of these actions, resulting in the Computer Software Components (CSCs) defined in Figure 3.1-1.
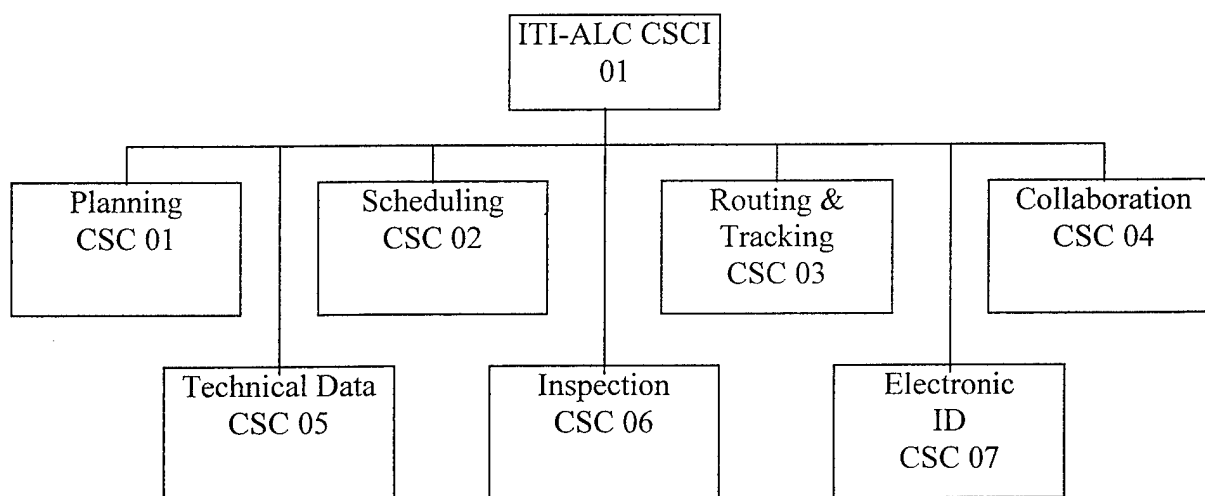
Figure 3.1-1. ITI-ALC Phase II CSC Decomposition

As the program matured and additional information became available on re-engineering activities, the prototypes for the planning, scheduling, routing and tracking areas were down scoped from the Phase II effort. When the program was shortened from 36 to 19 months, they were dropped altogether. The following sections will present the system architecture and design for the Collaboration, Tech Data Presentation, Inspection, and Electronic Identification CSCs.

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3.1.2 ITI-ALC System Architecture

The software and system architecture is presented in Figures 3.1.2-1 and 3.1.2-2.

Windows NT Server,
Oracle 7.3,
Internet Information Server,
Proxim RF LAN Driver,
Java Servlets (DHTML)
Mail Server

Fujitsu

Windows 95, Internet Explorer 4.0 SP1,
Proxim RF LAN Client Driver,
Handwriting Recognition S/W,
Adobe Acrobat PDF Viewer

Engineer's Desktop

Windows 95, Internet
Explorer 4.0 SP1,
Adobe Acrobat PDF Viewer
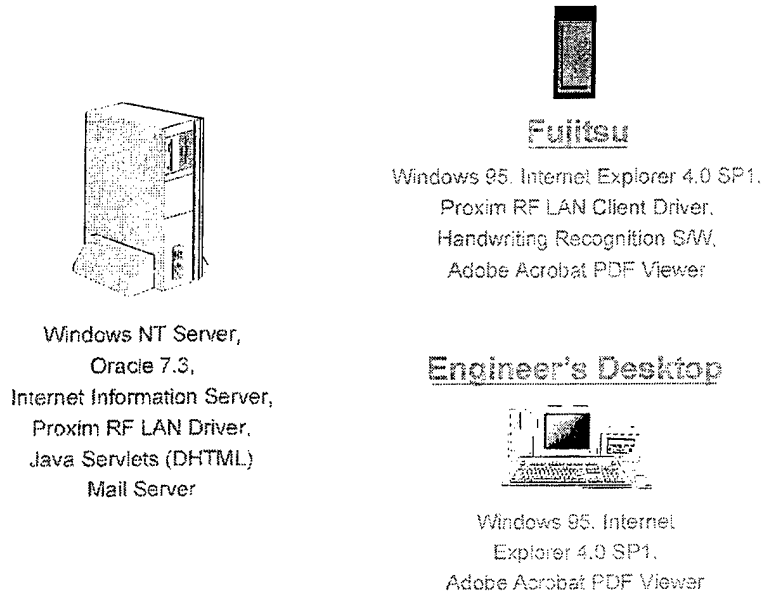
Figure 3.1.2-1. ITI-ALC Software Architecture
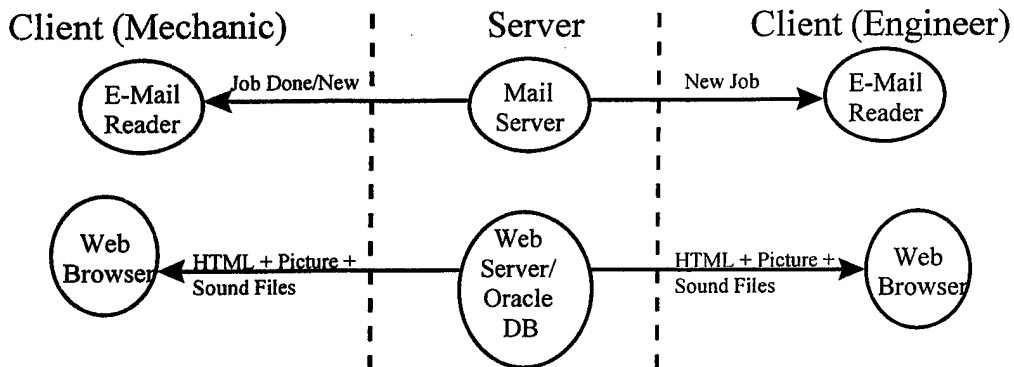
Figure 3.1.2-2. ITI-ALC System Architecture

Selection and implementation of a mobile computing platform suitable for the depot environment was a result of this evolutionary user centered effort. Three different mobile client platforms were implemented over the iterative life cycle of ITI-ALC Phase II. The Apple Newton, Fujitsu Point 510, and Fujitsu 1200 are shown in Figures 3.1.2-3 to 3.1.2-5.
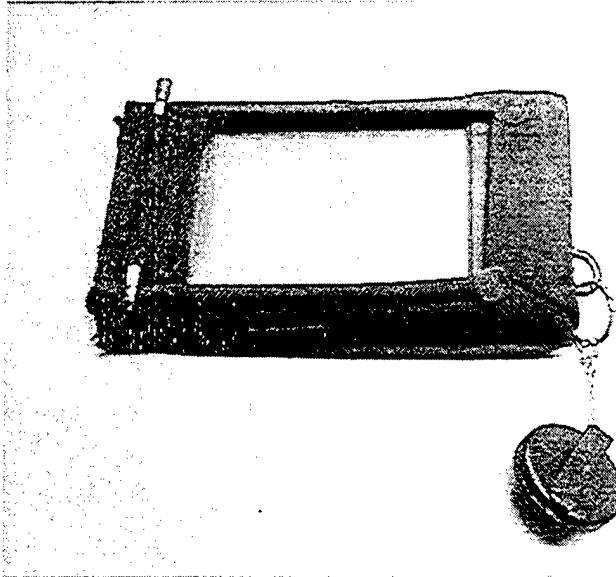
Figure 3.1.2-3.Apple Newton Client Platform
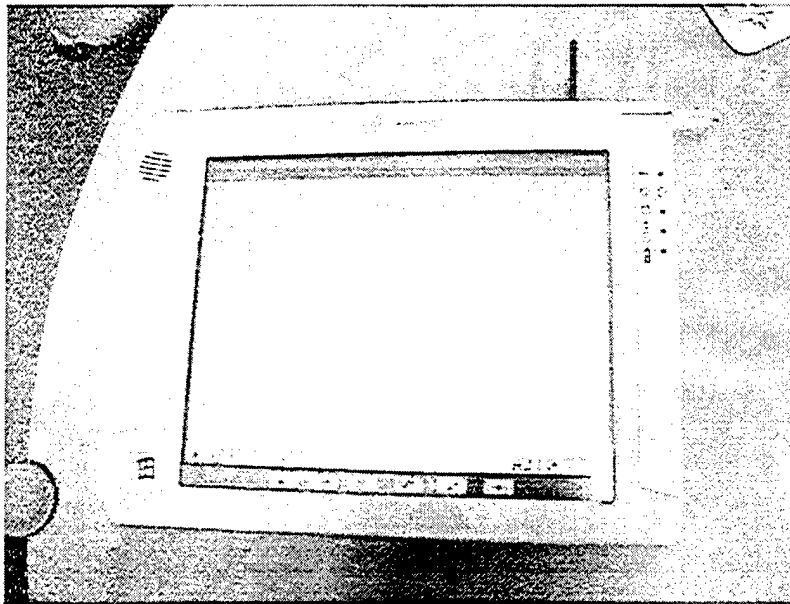
Figure 3.1.2-4. Fujitsu Point 510 Client Platform
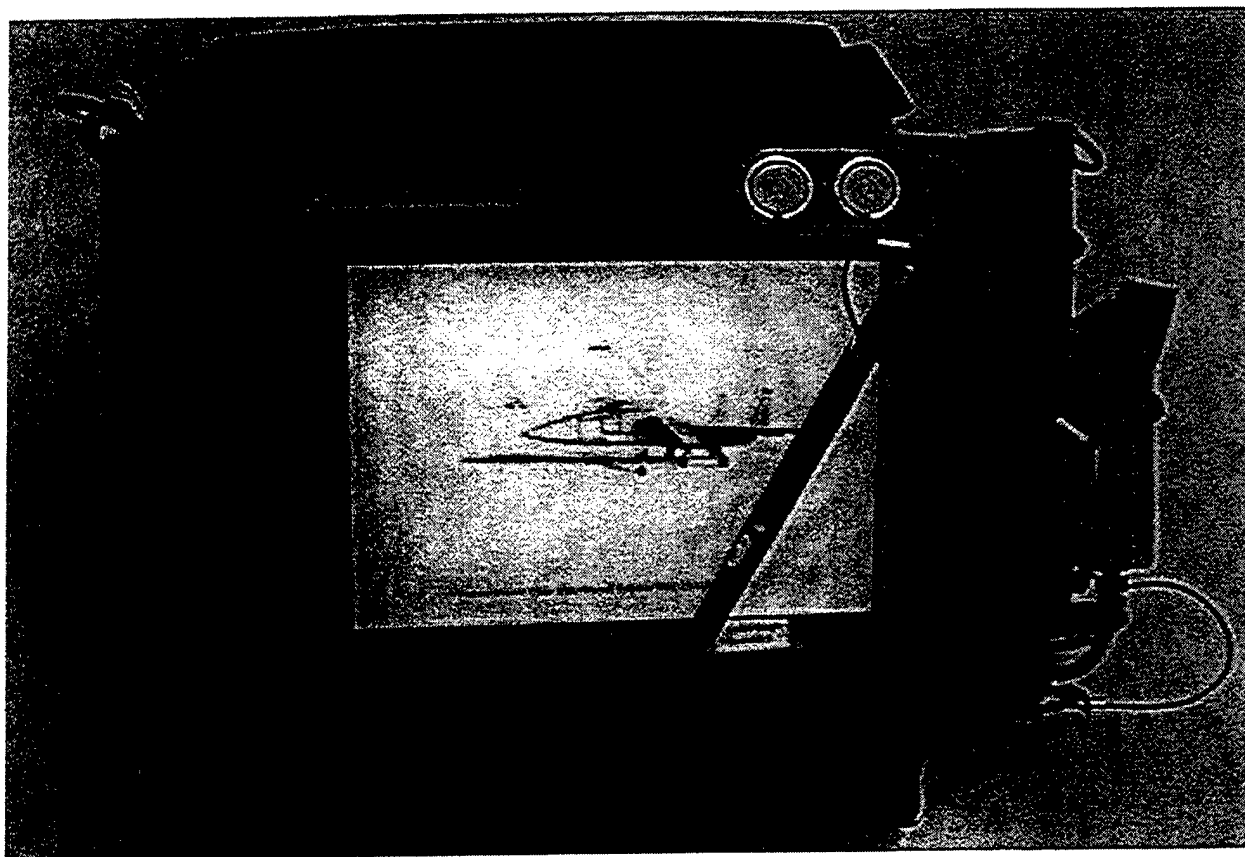
Figure 3.1.2-5. Fujitsu 1200 Client Platform

3.1.3. Collaboration Computer Software Component (CSC) Design

The Collaboration CSC design was implemented as presented in Figure 3.1.3-1.
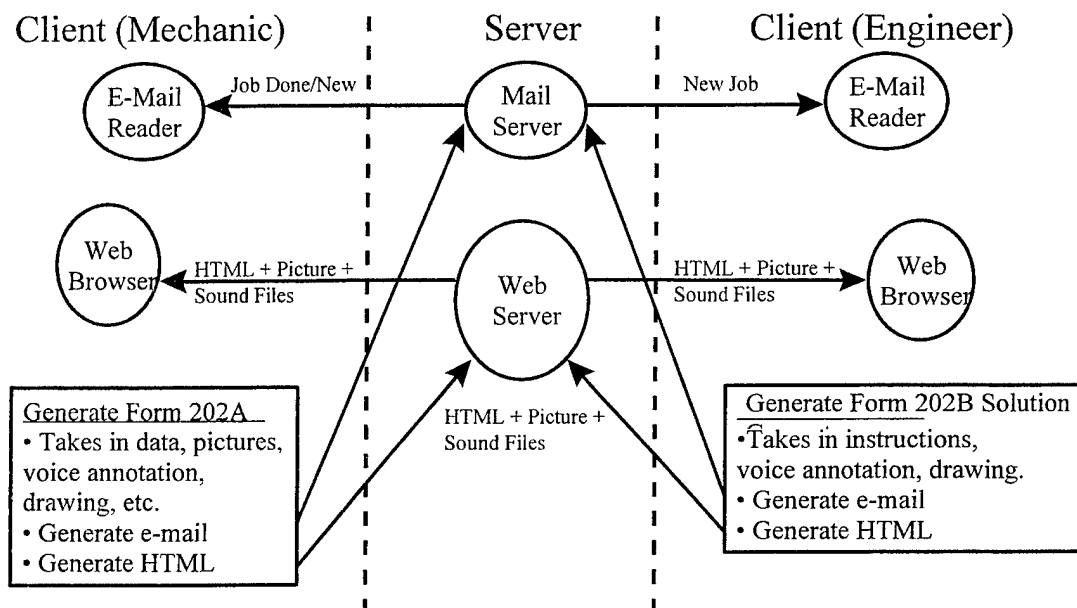
Figure 3.1.3-1. Collaboration CSC Architecture

The collaboration tool allows a mechanic to electronically submit an AFMC Form 202 (request for Engineering Assistance). This collaboration tool makes the AFMC Form 202 available to engineer within minutes, opposed to several days with the current process. The collaboration tool provides a method for a mechanic to create an engineering request form modeled after an AFMC Form 202. The form captures the mechanic identification, aircraft tail number, date and time, and a problem description. The collaboration tool provides a method for a mechanic to take a digital picture of the problem, annotate the picture, and include this digital picture with the engineering request form. The mechanic may also include a sound clip (a.k.a. Voice Note) or saved sketch with the Form 202.

The collaboration tool alerts (Figure 3.1.3-2) an engineer via e-mail to the existence of an open engineering request form. The engineer may then view and respond to the engineering request form from their web browser.

AFMC Form 202 Part A

Tap the parts icon to choose a part number from the aircraft drawing.
Tap the sketch or sound buttons to add these features to your request.
When Form 202 is complete, tap the send button to submit it to an engineer.

Part Number:

Tech Order: *************************** Select One ***************************

Work Stoppage: Yes ▼

Organically Caused: No ▼

Deficiency & Recommendations

Send

Figure 3.1.3-2. ITI-ALC Collaboration Tool Entry Screen

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3.1.4 Technical Data Presentation CSC

The Technical Data Presentation CSC design was implemented as presented in Figure 3.1.4-1.

Client (Mechanic) | Server | Client (Engineer)

Web Browser/Plugin ← HTML + IPDF TOs — Web Server — HTML + IPDF TOs → Web Browser/Plugin
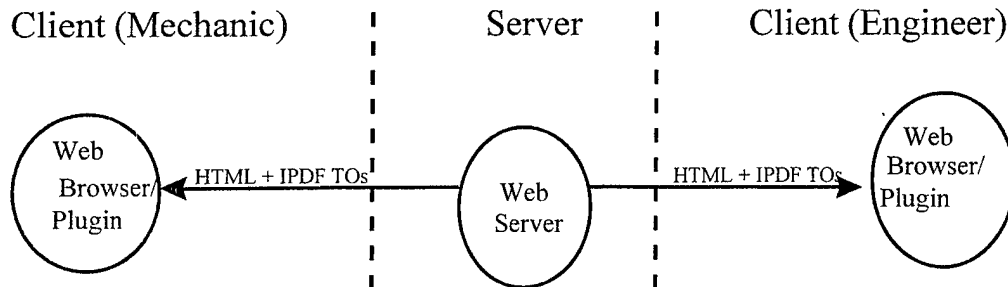
Figure 3.1.4-1. Technical Data Presentation CSC Architecture

The technical data presentation tool enables a user to electronically navigate and display technical manuals. The user (mechanic or engineer) is able to view electronic job guides, fault isolation manuals, and schematic and wiring diagrams. The tool supports multi-page technical manual diagrams. The tool allows the user to zoom in or zoom out of a diagram in order to place the currently displayed diagram section in context. The miniaturized ('zoomed in') view allows the technician to easily navigate from one diagram section to another. The technical data tool allows a user to select manuals by document title or category. The tool supports the ability to receive and display technical manuals from a server one page at a time.

The technical data tool's presentation format (Figure 3.1.4-2) is based on COTS World Wide Web document browsing technology (Internet Explorer 4.0) and COTS IPDF viewer plugin (Adobe Acrobat Reader).

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A

- ACCEPTANCE AND FUNCTIONAL CHECK FLIGHT PROCEDURES (1F-15E-6CF-1)
- ACCEPTANCE AND FUNCTIONAL CHECK FLIGHT (1F-15E-6CF-1)
- ACCESSORY GEARBOX SYSTEM - AIRFRAME MOUNTED ACCESSORY DRIVE S/S/SN 83-20-01 THRU 83-20-30 - JOB GUIDE (1F-15E-2-83JG-20-1)
- ACCESSORY GEARBOX SYSTEM - AIRFRAME MOUNTED ACCESSORY DRIVE S/S/SN 3-20-31 THRU END - JOB GUIDE (1F-15E-2-83JG-20-2)
- ACCESSORY GEARBOX SYSTEM - DRIVESHAFT - JOB GUIDE (1F-15E-2-83JG-10-1)
- ACCESSORY GEARBOX SYSTEM - GENERAL - JOB GUIDE (1F-15E-2-83JG-00-1)
- AEROSPACE GROUND EQUIPMENT - IPB (1F-15E-4-1)
- AIR CONDITIONING SYSTEM - DISTRIBUTION - JOB GUIDE (1F-15E-2-21JG-21-1)
- AIR CONDITIONING SYSTEM - FAULT ISOLATION (1F-15E-2-21FH-00-1)
- AIR CONDITIONING SYSTEM - GENERAL SYSTEM (1F-15E-2-21GS-10-1)
- AIR CONDITIONING SYSTEM - GENERAL - JOB GUIDE (1F-15E-2-21JG-00-1)
- AIR CONDITIONING SYSTEM - LIQUID COOLANT - JOB GUIDE (1F-15E-2-21JG-80-1)
- AIR CONDITIONING SYSTEM - PRESSURIZATION CONTROL - ANTI-G - JOB GUIDE (1F-15E-2-21JG-31-1)
- AIR CONDITIONING SYSTEM - PRESSURIZATION CONTROL - CABIN - JOB GUIDE (1F-15E-2-21JG-30-1)
- AIR CONDITIONING SYSTEM - PRESSURIZATION CONTROL - CANOPY SEAL - JOB GUIDE (1F-15E-2-21JG-32-1)
- AIR CONDITIONING SYSTEM - PRESSURIZATION CONTROL - WAVEGUIDES - JOB GUIDE (1F-15E-2-21SD-00-1)
- AIR CONDITIONING SYSTEM - SCHEMATIC DIAGRAM (1F-15E-2-21SD-00-1)
- AIR CONDITIONING SYSTEM - TEMPERATURE CONTROL - AIR CYCLE AIR CONDITIONING SYSTEM S/S/SN 21-64-01 THRU 21-64-21 - JOB GUIDE (1F-15E-2-21JG-64-1)
- AIR CONDITIONING SYSTEM - TEMPERATURE CONTROL - AIR CYCLE AIR CONDITIONING SYSTEM S/S/SN 21-64-22 THRU END - JOB GUIDE (1F-15E-2-21JG-64-2)
- AIR CONDITIONING SYSTEM - TEMPERATURE CONTROL - AVIONICS - JOB GUIDE (1F-15E-2-21JG-66-1)
- AIR CONDITIONING SYSTEM - TEMPERATURE CONTROL - BLEED AIR - JOB GUIDE (1F-15E-2-21JG-60-1)
- AIR CONDITIONING SYSTEM - TEMPERATURE CONTROL - CABIN - JOB GUIDE (1F-15E-2-21JG-65-1)
- AIRCRAFT AND EQUIPMENT - LIST OF APPLICABLE PUBLICATIONS (1F-15A-01)
- AIRCRAFT BATTLE DAMAGE REPAIR (1F-15E-39)
- AIRCRAFT DESCRIPTION AND MAINTENANCE ORIENTATION - GENERAL VEHICLE (1F-15E-2-00GV-00-1)
- AIRCRAFT - ENGINE AND JFS OPERATION S/S/SN 05-20-01 THRU 05-20-07 - JOB GUIDE (1F-15E-2-05JG-20-1)
- AIRCRAFT - ENGINE AND JFS OPERATION S/S/SN 05-20-08 THRU END - JOB GUIDE (1F-15E-2-05JG-20-2)
- AIRCRAFT - GENERAL MAINTENANCE S/S/SN 05-00-01 THRU 05-00-11 - JOB GUIDE (1F-15E-2-05JG-00-1)
- AIRCRAFT - GENERAL MAINTENANCE S/S/SN 05-00-12 THRU 05-00-23 - JOB GUIDE (1F-15E-2-05JG-00-2)
- AIRCRAFT - GENERAL MAINTENANCE S/S/SN 05-00-24 THRU END - JOB GUIDE (1F-15E-2-05JG-00-3)
- AIRCRAFT - EMERGENCY PROCEDURES - JOB GUIDE (1F-15E-2-05JG-30-1)
- AIRCRAFT LAUNCH INSPECTION PROCEDURES - WORKCARDS (1F-15E-6WC-2-2)
- AIRCRAFT LEVELING ...

Figure 3.1.4-2. ITI-ALC Tech Data Presentation Tool Entry Screen

3.1.5 Inspection CSC

The Inspection CSC design was implemented as presented in Figure 3.1.5-1.
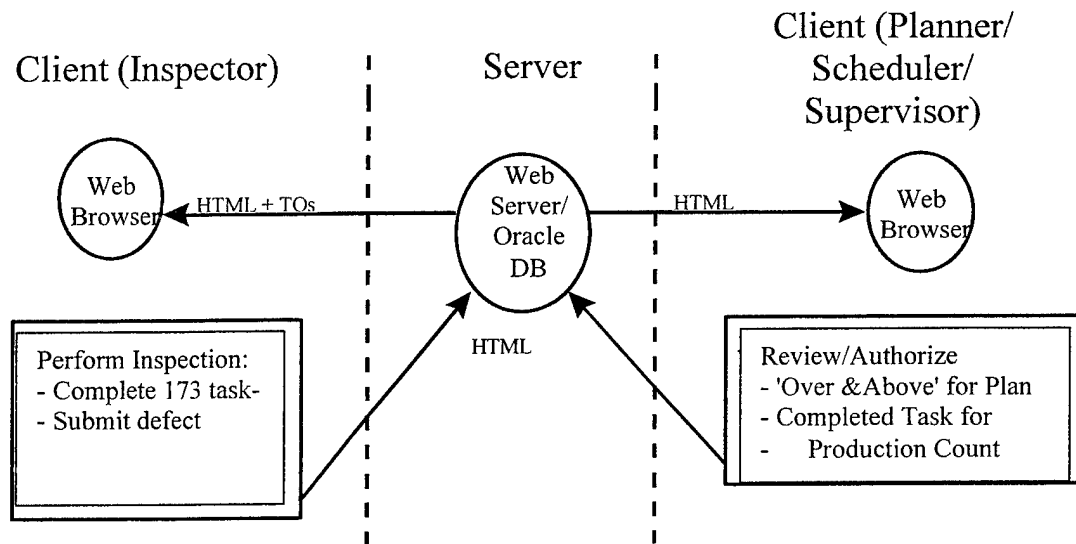
Figure 3.1.5-1. Inspection CSC Architecture

The inspection tool allows a technician to record defects and the areas of the aircraft on which the defects were found. The inspection tool implements the electronic ID tool to authenticate the user, both for security reasons and for the ability to assist in tracking and scheduling maintenance procedures. The tool provides a means to uniquely record which aircraft (and aircraft region) is being inspected. The inspection tool displays defects and options that are applicable to each area. The inspection tool has been populated with the most common aircraft defects (as identified by inspectors at the test site). These defects are available as selectable options. When a technician encounters a defect that is not already an option, the inspection tool provides them with a method for adding an ad-hoc defect. This implementation discourages the widespread creation and use of ad-hoc defects, a detriment to later defect analysis. The mobile inspection tool client platform (Fujitsu 1200 Tablet computer) has been chosen (and tailored) to allow the inspector to take it directly to the aircraft area that is being inspected. The inspection tool records technician-identified defects of each area in a repository (Oracle database). This repository format allows for the potential to export the collected data to the scheduling system, allowing the repair of defects to be planned and scheduled. As an interim step, the repository will be used to a display the identified discrepancies and completed 173 inspection steps.

The inspection tool's display format (Figure 3.1.5-2) is based on COTS World Wide Web document browsing technology (Microsoft Internet Explorer 4.0SP1).

Tap an area number or scroll through this list to view work cards.
Tap the circle icon to the right of each task to select it.
To view the list of all checked task, tap the signoff icon.

01 = Forward Fuselage, Radome and Speed Brake

12621	Visually inspect the left side load scissors for cracks, wear and corrosion. IAW. 1F-15A/C/E-3-4
12622	Visually inspect the right side load scissors for cracks, wear and corrosion. IAW 1F-15A/C/E-3-4
12643	Visually inspect radar antenna for hydraulic leaks, cracks, corrosion and any other defects. Defects will be annotated on AFLC Form 173
12657	Inspect radome hinge and radome hinge back up angle for warping, cracks, corrosion and missing fasteners. IAW 1F-15A/E-6WC-6 and 1F-15A/C/E-3-1. (1200 hour inspection).
12660	Visually inspect upper and lower fuselage splice area, F.S. 416 for cracks and loose or damaged fasteners. Check skin for dents, cracks and buckles. (1200 hour inspection).
12666	Visually inspect the left and right diffuser ramp fixed hinge supports, using a mirror and flashlight, for cracks. Check the servocylinder for leakage, corrosion and cracks. (1200 hour inspection).
12684	Visually inspect aileron rudder interconnect (ARI) for leakage. Inspect support bracket for cracks and scurry. Inspect electrical connectors for chafing and

Figure 3.1.5-2. ITI-ALC Inspection Tool Entry Screen

3.1.6 Electronic Identification CSC

The electronic identification tool (Figure 3.1.6-1) provides a means for an individual to be uniquely identified to each of the previously described mobile client prototype tools. This identity is then used to tailor the each tool to the individual. For example, if an individual is an inspector, only the inspectors' 173 inspection tasks and defects are presented. If the individual is a sheet metal mechanic, the option to submit a request for engineering assistance (Form 202A) is presented. The electronic identification tool has been implemented using the iButton technology. This tool also provides a paperless means of 'stamping off' on the completion of 173 inspection tasks, which is similar to the currently implemented physical 'stamp' methodology. The tool typically completes determination of the identification of an individual within 5 seconds. Because each electronic iButton has a unique identifier, the tool will accurately identify the individual 100% of the time, and is not physically 'intrusive' to the individual. The chosen tool is capable of operating in the hangar environment, as the typical temperature, humidity, lighting, and ambient noise in that environment will have no effect on the identification of each physical iButton.

Please Insert Your Electronic Stamp Into The Receptor.
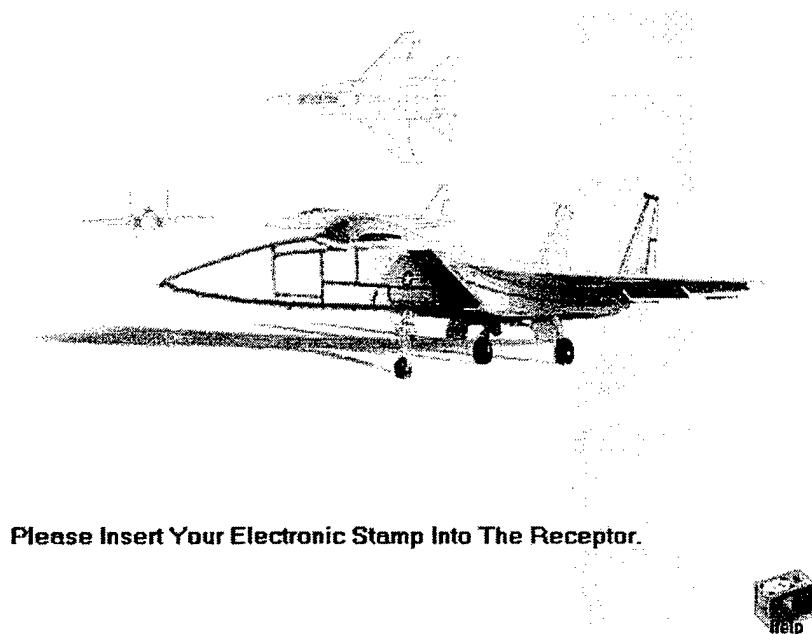
Figure 3.1.6-1. ITI-ALC Client Logon Screen

3.2 Supporting Trade Studies

The trade studies performed under the ITI-ALC contract are provided in Appendix A. They capture quantitative and qualitative data about the different products researched by the ITI-ALC team. The trade studies include a summation of the trade identifying the best candidate, any metrics or test data collected during the trade, a trade study assessment table for each product or tool being studied, experience with the products, and product data sheets (marketing information) from the vendors.

3.3 Description of Maintenance Tasks

During FBE #1 the user group indicated that they expected ITI-ALC Phase II resources would be used most productively on developing prototypes to support their work in three areas. The three depot maintenance tasks identified were:
(1) Recording and distributing Evaluation and Inventory Inspection information.
(2) Documenting and communicating/collaborating between skin mechanics and engineers about situations requiring engineering assistance (Over and Aboves), especially for vertical tail assemblies on the F-15 aircraft.
(3) Enabling effective collaboration among technicians conducting operational checkouts on an aircraft.

The ITI-ALC team documented the "as is" current situation for each of these three application areas immediately after FBE #1. Two of the three areas were selected, demonstrated, and evaluated using these depot maintenance tasks:
(1) Evaluation and Inventory (Inspection)
(2) Collaboration about "Over and Aboves" for the Vertical Tail Assembly of the F-15.
The third area was not pursued, due to the heavy dependence on electronic technical data, especially schematic drawings, which proved to be problematic to acquire for ITI-ALC Phase II use.

Visionary scenarios for each of the two application areas were developed and reviewed by the user group. These scenarios served as the basis for the development, evaluation and measurement efforts for ITI-ALC Phase II as they provided a clear indication of the functionality and performance support capabilities users would expect from the technologies used in each prototype system. Each of the tasks and the usability evaluation efforts associated with the ITI-ALC Phase II development efforts are described below.

3.3.1 Evaluation and Inventory (E&I) Task Description

This study evaluated the impact of the E&I prototype on aircraft inspections being conducted when the aircraft reaches the Mod-Dock phase of the PDM cycle. The complete evaluation and inventory inspection task involves ninety-three 173 cards, and is expected to be completed within a ten-day period. The individuals who perform this inspection walk around the aircraft, and use ladders to climb into the cockpit, or to view the fuselage above eye-level. They visually and tactilely examine each plane section by section. The inspection tasks differ in terms of length and complexity, and are almost always a single person effort. However, the current F-15 inspection arrangement at Robins AFB involves a two-man team comprised of a very experienced inspector and a novice inspector. There appear to be personal differences in the approach/process that inspectors use in conducting this work. Also, the order and sequence of aircraft sections they work on varies from one aircraft to another and from one inspector to another. Overall, the major time associated with this task has been in entering, verifying and communicating the inspection findings to generate work for others. That is, the inspection findings result in parts ordering and scheduling of work tasks for appropriate mechanics.

3.3.1.1 Scope of E&I Task

The ITI-ALC Phase II E&I inspection tool was designed to enable inspectors to easily observe and record defects from any of the 15 regions they normally consider on the F-15 aircraft. After careful consideration of several factors, including safety and task complexity, two areas of the aircraft were selected for testing the usability of the prototype during FBE #2, the shakedown exercise and the final user evaluation. The regions the E&I inspectors used were (1) the cockpit (areas 2 and 2A of the aircraft) and (2) the engine compartments (areas 12 left and right of the aircraft). These aircraft areas were selected in consultation with first line supervisors and inspectors at WR-ALC. (Section 9, Aft Fuselage, was not considered since this area of the aircraft was involved in the FBE #2 Collaboration prototype demonstration and evaluation.) Table 3.3.1.1-1 shows the regions of the aircraft identified for use in the E&I inspection prototype efforts.

Table 3.3.1.1-1. F15 Aircraft Inspection Regions

Region	Description
01	Forward Fuselage, Radome and Speed Brake
1A	Nose Gear, Well and Doors
02	Forward Cockpit
03	Left Engine Intake Duct
04	Right Engine Intake Duct
05	Left Wing
06	Right Wing
07	Center Fuselage and Fuel Cell
7A	Left Main Gear, Well and Doors
7B	Right Main Gear, Well and Doors
09	AFT Fuselage
10	Left Engine
11	Right Engine
12	Engine Compartments
13	Aircraft General

The users evaluated the prototype system to determine its acceptability and its potential impact on reducing inspectors' effort associated with inspecting and recording E&I data. The version of this tool developed for the final user evaluation exercise enabled measurement of the impact of transmitting the E&I data to those who use it, e.g., planners and schedulers. That is, the prototype supports export of the E&I inspection data for integration with WR-ALC legacy systems (in particular, Programmed Depot Maintenance Scheduling System (PDMSS)). A task overview is presented next to provide the reader with a sound understanding of the activities involved in E&I inspection.

3.3.1.2 E&I Task Overview

For the E&I task, an inspector conducts a visual examination of the aircraft exterior (skin, canopy, etc.) and records the status of the aircraft panel or component. Also, aircraft parts are inventoried so that missing/worn parts information could be passed to the Forward Logistics Specialist (FLS) to order/obtain parts to expedite the aircraft's progress through the Mod-Dock phase. The inspector selected a section of the aircraft to evaluate (in the case of FBE #2, the researchers selected the sections as noted above). Inspectors' tools are comprised of a flashlight and/or mirrors they may use while doing the tasks. For the baseline (without technology) condition, they had available (but did not use) a paper checklist of frequently found defects (Figure 3.3.1.2-1) with data fields to record: the aircraft area, the station, the skill required to do the repair, and a brief description of the discrepancy. Inspectors went to the section of the aircraft to be inspected, performed the inspection, and logged it in their workbook (Figure 3.3.1.2-2). They later recorded their work by stamping the appropriate 173 work cards (Figure 3.3.1.2-3).

F = REQUIRED OPN

RECORD NO. 1

DISCREPANCY
FWD END OF HINGE CRACKED ON AIRCRAFT ABOVE
DOOR 3E

AREA	STA.	SKILL	
01	0	AS	3E-15A-3-2

F = REQUIRED OPN

RECORD NO. 2

DISCREPANCY
FWD END OF HINGE CRACKED ON AIRCRAFT ABOVE
DOOR 3E

AREA	STA.	SKILL	
01	0	AS	3F-15A-3-2

F = REQUIRED OPN

RECORD NO. 3

DISCREPANCY
AFT END OF HINGE CRACKED ON AIRCRAFT ABOVE
DOOR 3E

AREA	STA.	SKILL	
01	0	AS	3E-15A-3-2

F = REQUIRED OPN

RECORD NO. 4

DISCREPANCY
EACH ADEL CLAMP HAS DETERIORATED INSULA-
TION ON ELEC. WIRE TO RT FORMATION LIGHT,
UNDER FWD END OF DOOR 4E

AREA	STA.	SKILL	
01	0	AC	3F-1A-14

F = REQUIRED OPN

RECORD NO. 5

DISCREPANCY
RAIN SEAL TORN ON AIRCRAFT UNDER DOOR
4 1E AT HINGE POINT

AREA	STA.	SKILL	
01	0	AS	3E-15C-3-2

F = REQUIRED OPN

RECORD NO. 6

DISCREPANCY
RAIN SEAL TORN UNDER HINGE ON AIRCRAFT DOOR
1E

AREA	STA.	SKILL	
01	0	AC	3F-15A-4-3

Figure 3.3.1.2-1 Sample of E&I Frequent Defect List

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Figure 3.3.1.2-2 Sample of E&I Workbook Entry

AFMC FORM 173, SEP 92   REPLACES AFLC 173, SEP 79 WILL BE USED   MDS/PROJECT OPERATION ASSIGNMENT

Figure 3.3.1.2-3 Sample of E&I 173 Inspection Work Card

These inspectors did not record responses to each possible defect item on the checklist. When new/infrequent defects were seen, they wrote a brief description of such defects on a new 173 card, and indicated that these would be manually entered later into the U-book by the scheduler (Figure 3.3.1.2-4).

Note that inspection of a given section/panel of the aircraft varies greatly with respect to the time to complete each task (5 minutes to an hour).

Figure 3.3.1.2-4 Sample of E&I Defect Worksheet Entry

3.3.1.3 Defects Used for the E&I Task

No physical defects were inserted for any of the events. For both the baseline and with technology cases, the selected aircraft had not been inspected. The aircraft was selected in consultation with the aircraft supervisor who anticipated that real defects would be present. No additional defects were needed (or inserted) by test personnel for this evaluation. Defects present (and found by the inspectors) during FBE #2 were small cracks in the engine compartment, sections 12 left and right and some corrosion in the cockpit, sections 2 and 2A.

3.3.2 Collaboration (Engineering Assistance) Task Description

This task involves collaboration over time and distance between two or more individuals. The activities of skin mechanics who are seeking engineering assistance to determine a course of action for handling "Over and Above" defects should be supported by the introduction of an ITI-ALC Phase II prototype. These activities include prompt sending and receiving of textual information, sketches and measurement information as well as references to Technical Orders (TOs). The specific task used in FBE #2, the shakedown exercises, and the final evaluation was the resolution of defects found on the vertical tail assembly of an F-15C aircraft.

3.3.2.1 Scope of Collaboration Task

To determine the scope of this task, the ITI-ALC Phase II team conferred with the supervising structural engineer to determine which areas of the F-15 aircraft structure have the most frequent occurrence of "Over and Above" defects. Also, the F-15 first line supervisor and several skin mechanics were consulted about the area of the aircraft to select for the field-based evaluation activities. The vertical tail assembly of this aircraft was identified as the appropriate area to use in the Collaboration (Engineering Assistance) prototype. According to historical data available from the supervising structural engineer, on average, thirty requests for engineering assistance are generated each month for this section of the aircraft. The Non-Destructive Inspection (NDI) engineer consulted during the ITI-ALC Phase II effort also endorsed this selection of aircraft area. The following Figure 3.3.2.1-1 shows this section of the aircraft.
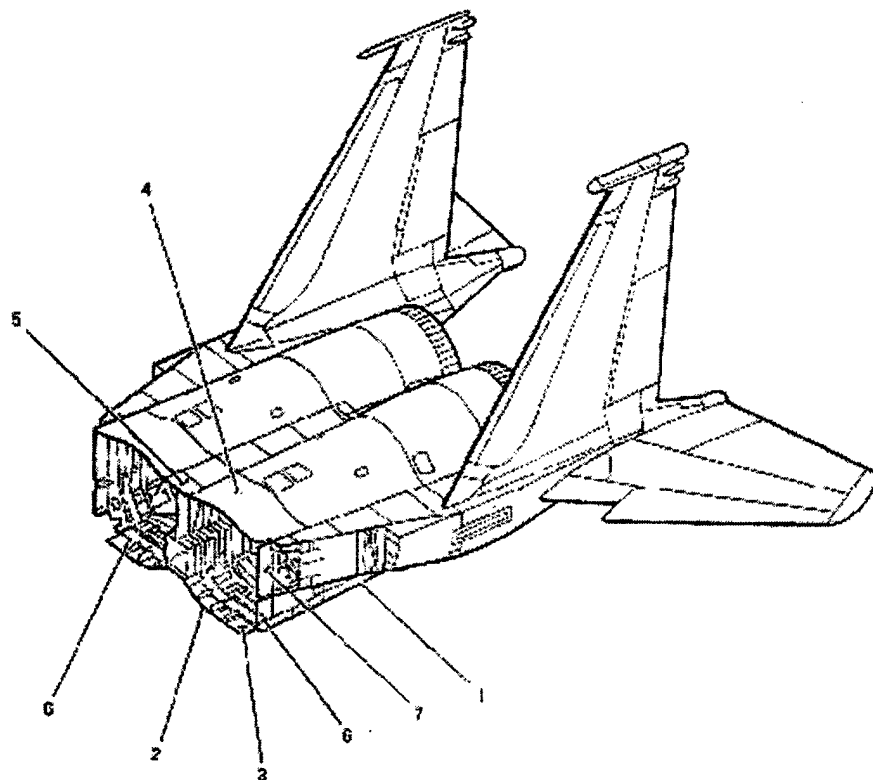
Figure 3.3.2.1-1 Vertical Tail Assembly for Collaboration Prototype

Evaluation of the Collaboration prototype was aimed at gaining feedback from actual users about the acceptability and potential impact of efficiency gains they could expect to realize using such a prototype.

A task overview is provided next to insure that the reader has a detailed understanding of the tasks the ITI-ALC prototype supports for skin mechanics and structural engineers.

3.3.2.2 Collaboration Task Overview

During the disassembly phase of the planned depot maintenance process, a skin mechanic notices that there is an apparent crack in the vertical tail assembly of the plane and believes that it needs to be repaired. Because this repair is not in the Technical Orders, the mechanic must request direction and approval to do this repair. He obtains and completes Part A of a Form 202 (Figure 3.3.2.2-1), Engineering Assistance Request, describing the location and nature of the defect - often including a rough, hand-done sketch. A scheduler and a planner log the form. They (along with a first-line supervisor) decide whether the form should be sent to Engineering. If the aircraft schedule will be

seriously impacted by this repair activity, then the form may be faxed or hand carried to Engineering (about 4 long blocks away from the F-15 hanger). When it is sent, the structural engineering supervisor assigns the Form 202 to an engineer who visits the hanger to inspect the defect, calls the technician to ask about the severity of the defect, or simply determines from the Form that a repair is required.

NONCONFORMING TECHNICAL ASSISTANCE REQUEST AND REPLY

SM MAINTENANCE

PART A

1. TO	2. FROM	3. DATE	4. CONTROL NUMBER
LFE	LFPSM	13 Mar 98	LFPW 98093A

5. NOUN	6. PART NUMBER	7. NATIONAL STOCK NUMBER	8. SERIAL/TAIL NUMBER
RIGHT VERTICAL			F 15 E 86 - 156

9. LOCATION	10. TO/DWG NUMBER	11. WORK STOPPAGE	12. INITIATOR (Signature/Office Symbol/Phone)
BLDG 83		[X] YES (Date) [ ] NO	NDI

13. NOTIFIED TECH CONTENT MANAGER (TCM) (Office Symbol/Date/Time)	14. ORGANICALLY CAUSED	15. MAINTENANCE PLANNER/ENGINEER (Signature/Office Symbol/Phone)
	[ ] YES [X] NO	LFPW

16. DEFICIENCY AND RECOMMENDATIONS

OPERATION # 95006: RT VERT LOWER AFT BOX HAS AN AREA OF CORROSION REF FIG 4-37 FILM 1R IAW 1F15A-36

17. TO	18. FROM	19. DATE	20. ENGINEER/ES (Name/Office Symbol/Phone)
LFPSM			

21. DISPOSITION INSTRUCTIONS

[ ] USE AS IS [ ] CONDEMN [ ] REWORK [ ] PLACE IN ACCOUNT NUMBER [ ] N/A

22. REPAIR INSTRUCTIONS

23. RECISSIONS A. DATE: B. COMPLETION OF S/N:	24. REQUIRES AFMC FORM 252 [ ] YES [ ] NO REQUIRES AF FORM 2600 [ ] YES [ ] NO

25. AFTO FORM 95/DD FORM 1574 ENTRY

26. COORDINATION/APPROVAL

A. ENGINEER/ES	D. TO MANAGEMENT OFFICE
B. SAFETY	E. ENGINEER/ES BRANCH CHIEF
C. PRODUCT ENGINEER	F.

AFMC FORM 202, APR 94 (EF)   PREVIOUS EDITION IS OBSOLETE

Figure 3.3.2.2-1 Sample of Air Force Material Command (AFMC) Form 202

The engineer completes Part B of the form (Figure 3.3.2.2-1) and specifies the appropriate repair, including drawings of the approved fix. This information is either hand delivered or faxed to the technician in the hanger. The technician executes the repair, but often needs to clarify what the engineer advises by calling or requesting a visit to the hanger from the engineer. The technician works from a platform ladder about 15 feet above the hanger floor, at the tail of the plane. The elapsed time associated with the Form 202 process for vertical tail assembly defects has been, on average, seven to ten days.

3.3.2.3 Defects Used for the Collaboration Task

An aircraft was selected in consultation with the aircraft supervisor from the F-15 line for FBE #2, for the shakedown exercise and for the final evaluation. There were defects identified by Non-Destructive Inspection (NDI) group, but not yet seen by the skin mechanics participating in the prototype usability testing. These defects included corrosion and cracks. No additional physical defects were needed (or inserted) by test personnel for these evaluations.

3.4 Study Participants

The participants that contributed to this study consist of individuals from AFRL/HESR, Lockheed Martin, Carnegie Mellon University, PDM flight line supervisors, planners, schedulers, inspectors, mechanics, and engineers that make up the DE and DD IPTs. DE IPT teams conducted most user-centered events. Each team would be comprised of an interviewer/observer/researcher from Carnegie Mellon University (CMU) and a videographer. In the cases in which training was administered, each team would use a prepared script to insure consistency in training. Additional Demonstration Development (DD) IPT personnel provided support for network and platform performance issues at selected events. The interaction of the additional personnel with study participants was minimal.

3.5 Data Collection Procedures

At the inception of the Field-based Evaluation efforts, each participant completed a non-disclosure form and an initial questionnaire containing demographic and background information for use in the study. Then interview data were collected via audio and video recording, and researchers' observations. Also, substantial archival data were collected, e.g., blank and completed paper forms, schedules of aircraft movement through PDM, spread sheets showing current processes, etc. During FBE #2, the shakedown exercise and the final evaluation effort, additional data collection efforts occurred. These are described in the sub-sections to follow.

3.5.1 Usability Study Events

In February and March 1998, "without technology" (baseline) and with technology trials of the ITI-ALC Phase II prototypes were conducted. The main purposes of these trials were: (1) to determine modifications required in the iterative development process and (2) to begin to collect data about the potential impact of these prototypes on mechanics' and engineers' work processes and task performance.

Four major sources of data were drawn upon during FBE #2:

- Video/audio taping of actual behavior,
- Automated data logs of user behavior (client and server time stamped histories of most interactions)
- Survey/interviews eliciting users' subjective reactions to ITI-ALC prototypes, and
- Observational evaluation: watching and monitoring users' performance of specific tasks (enacting each scenario) with the ITI-ALC prototypes.

Specific data collection was done primarily for usability feedback to the developers and included efforts to measure:

- time for sub-task and task completion (e.g., finding information needed, completing inspection of an area, marking a defect),
- quality of task performance (is the inspection performed thoroughly etc.),
- amount and usability of information available to maintenance personnel,
- the flow of information (do people follow their process or change it when using the prototypes),
- the amount and nature of assistance needed to use the prototype(s),
- the ease of movement (mobility) of users with prototypes, especially in confined or hard to reach/maneuver-in spaces, and the ease of use of prototypes in variable lighting, temperature, noise and other conditions on the PDM line.

For the survey effort, a post-questionnaire (Appendix B) was administered to elicit inspectors' or skin mechanics' reactions immediately following use of the prototype systems. This instrument included both open and closed questions. This was also supplemented with written questionnaires with limited, structured interviews that were audiotaped for transcription to insure accurate analysis of verbal feedback.

For the observational effort, rigorous video recording of training and use sessions was conducted to capture detailed, time-stamped records of technicians' performance during task execution. These data were correlated with the automatically collected data to show how the prototype was used at any given moment. Additionally, verbal protocols (think-alouds) were elicited to capture each technician's spoken observations and thoughts as they used the prototype.

3.5.1.1 Usability Procedures

The following procedures were employed to evaluate usability of each of the prototypes. During the first (baseline) session, technicians were briefed about the overall evaluation process and those who were not involved in FBE #1 filled-out the initial questionnaire. Each technician then performed the baseline task. During the technicians' performance, one researcher videotaped while the other observed and filled-out the performance observation form. The technicians were prompted, as needed, to provide think-aloud protocols while performing their tasks. For the E&I Inspection task, one technician performed the cockpit inspection while the other performed the engine compartment inspection. Then they switched locations on the same aircraft. For the "with technology" condition, technicians were introduced to the prototype system. This consisted of a practice session with both the handwriting application, and the overall interface prior to using the prototype.

Upon completion of their tasks, the post-questionnaire was administered to get feedback and debrief the participants. On the baseline visit (without technology), the participants were briefed with just the purposes of the return trip (with technology) and what activities they would be expected to perform. The debrief also set expectations with the technicians for a follow-up evaluation of improved prototypes in the future.

3.5.2 Shakedown Event

In July 1998 an evaluation event aimed at determining the stability and maturity of the ITI-ALC Phase II prototypes was held at Robins AFB. The USAF sponsor who sent a team to observe user and prototype performance specified criteria for success for this trial. In addition to observer checklists, video and audiotaping of the training and actual task performance trials of users was done. Finally, detailed time coding of elapsed time to do subtasks was recorded for each participant.

3.5.2.1 Shakedown Procedures

Each of four participants completed a consent to participate form and an initial questionnaire providing demographic information, data about their prior experience in the job, and self-rating of their previous computer experience. Then, using the prototype, each person underwent extensive practice to learn to use the handwriting recognition software and the pop-up keyboard available at the time of the shakedown. Once mastery of the data input capabilities of the prototype were established, each participant was trained by an LMIS team member to use the prototype for the E&I or Collaboration tasks. After completing the tutorial with assistance, each participant proceeded to use the prototypes independently and all four participants did so. On completion of the task, each participant completed a post-questionnaire indicating what they liked and disliked, and what they would recommend changing about the prototypes.

3.5.3 Final Field Trial

Goals

A final field test was conducted in Oct '98 at Warner-Robins AFB to evaluate PDM efficiency, operating costs and technician performance while using the ITI-ALC system. Thorough evaluation of the ITI-ALC system warranted inclusion of several field test goals. Additionally, these goals had to be evaluated under certain field test constraints. The goals were:

- Validate the concept of an ITI-ALC system
- Evaluate the ITI-ALC system in its ability to address the Business Process Improvements identified from Phase I activities (i.e., its ability to lower operating costs)
- Evaluate the ability of an ITI-ALC system to improve job performance
- Identify specific improvements that can be made to the hardware and software for future ITI-ALC system implementation programs.
- Provide lessons learned for development of an ITI-ALC system.

Developing and conducting research in an applied setting, such as a working ALC, often has unique constraints. These constraints apply to field test procedures, data collection activities, time considerations, and subject pool. For this field test, operational constraints included:

- Limited access to aircraft locations (e.g., climbing on top of the aircraft).
- Time measurements were not taken due to the fact that demonstration tasks were merely segments of a process—total process time could not be measured.
- Due to time constraints, two simpler applications were developed for the demonstration. An Evaluation and Inventory Inspection (E&I) application and a Collaboration 202 Form application.
- Participants used for the field test were selected by and asked to participate by their supervisor.

METHODS

Participants

The ITI-ALC field test included eleven participants. Three inspectors used the ITI-ALC system to perform E&I inspections. Six sheet metal mechanics used the ITI-ALC system for the Collaboration application—to generate a 202A request form. Two engineers, one a supervising engineer, used the ITI-ALC notebook system to generate a response to the 202A form (i.e., the 202B form).

Eight of the eleven participants participated in a previous ITI-ALC prototype demonstration. One inspector and two mechanics had not used the system prior to this field test.

Inspector's years-of-experience ranged from 1½ to 13 years. Mechanic's had between 10 and 17 years of experience. Engineers declared between 11 and 14 years of experience on the job.

For the eleven participants, one mechanic and both engineers indicated that they had quite a bit of experience with computers. The remaining eight had no or very limited experience with computers.

Apparatus

The system consisted of a server and several mobile computer systems, which network to the server via wireless access points. The server system supports servers for HTTP, FTP, SMTP, and POP3 connections and traffic, and for database connectivity. The mobile systems connect to the network directly via the wireless access points. The wireless systems require support for all of these protocols.

Hardware

A portable system has been configured as a server for off-site demos. The system is a Dell Inspiron M233XT, and is configured as follows:

- Pentium 233Mhz processor
- 48MB RAM
- 11/20X CD ROM
- 3.2 GB HD
- 13.3" XGA display
- Sound system with built-in microphone and speakers
- Proxim PC card 2.4 GHz radio w/snap-on antenna

Clients. The hardware for the ITI-ALC clients, Fujitsu Stylistic 1200 pen tablets, were as follows:

- Pentium 120MHz processor
- 32MB RAM
- 1.6 GB HD
- 8" Thin Film Transistor (TFT) color display
- Sound system with built-in microphone and speakers
- Proxim PC card 2.4 GHz radio w/snap-on antenna
- ViCAM PC digital camera
- iButton reader

Software

Server. The portable server operating system is Windows NT server, version 4.0, with service pack 3, option pack 4. Additional software packages installed included:

- Internet Information Server (IIS) 2.0
- Oracle Server V7.3
- Live Software JRunIIS
- Ipswitch Imail
- Internet Explorer 4.0, Service Pack1
- ITI-ALC server application software and database
- Adobe Exchange 3.0 with activeX plugin and compose
- Proxim RF PC card drivers
- NeoMagic Display drivers
- CrystalWare Audio drivers
- RangeLan2 utilities

<u>Clients.</u> The system software for the ITI-ALC clients is Windows 95. Additional software installed on the clients included:

- Pen services for Win95
- CIC handwriting recognition
- Neo-Magic video drivers
- ESS sound drivers
- RangeLan PC card drivers
- Adobe Exchange 3.0 with active X plugin
- Internet Explorer 4.0, Service Pack1
- Eudora light mail client
- ViCAM PC digital camera drivers
- iButton server software
- ITI-ALC client application software

Data Collection Materials

Four data collection techniques were used to collect subjective information from test participants. The first technique, a questionnaire, targeted specific questions relevant to the ITI-ALC system. The questionnaire was divided into three general areas: the ITI-ALC concept, the perceived effect of an ITI-ALC system on job performance, and usability of the hardware and software. The second technique was observation. As participants used the system, test administrators collected notes on how each person used the system and areas where difficulties were encountered. The third technique, interviews, enabled each participant to provide detail on their responses to the questionnaire and clarification of problems encountered during the tests. The final technique required each participant to "walk-through" the application using a paper prototype. As the technicians observed each prototype screen, they provided comments to the interface.

Procedure

Upon arrival, subjects signed an AFRL/HESR consent form. Next, they participated in a tabletop training session in which each of the ITI-ALC screens was shown and functions were identified. Participants were taught how to use the pen to interact with the various ITI-ALC screens. Each participant was fitted with the ITI-ALC hardware to assure straps were of proper length. Training sessions ranged from approximately 1 to 2 hours per participant.

Following training, the inspectors and mechanics proceeded to the hangar floor where they used the ITI-ALC system to perform the E&I and Collaboration tasks while at an aircraft. Inspectors and mechanics were free to pick areas on the aircraft to for inspection or 202A write-ups; however, the ITI-ALC scenarios (e.g., only certain areas on the aircraft were authored for the scenarios), safety considerations, and actual PDM activities restricted aircraft area selection. For approximately 45 minutes, the inspectors and mechanics used the ITI-ALC system. Assistance on how to use the ITI-ALC system was limited to two types. First, the test administrator assured that participants used all functions available in the application. Second, if the participant had trouble with a function, they were given help only as required. Help was limited, in most cases, to verbal assistance.

Engineers participated in tabletop use of the ITI-ALC system to perform the Collaboration task. They responded to 202A forms generated by the mechanic participants earlier in the field test. In this way, data on the 202A forms were somewhat representative of the types of data actually available through an ITI-ALC system.

Following the field test activities, participants filled out a questionnaire (see Appendix C), discussed their responses to the questionnaire with the test administrator, and commented on each of the ITI-ALC screens (Appendix E and Appendix F).

4. Results and Discussion

4.1 FBE # 1 Formal Usability Study Event

FBE #1 began the user-centered, iterative development cycle for ITI-ALC Phase II. During this event, ten users who varied in terms of domain expertise and personal traits (education, vision, physical size, age, etc.) provided updates to the ITI-ALC Phase I user requirements and commented on potential technologies shared with them during FBE #1. (For a detailed account of this activity, please see ITI-ALC Phase II FBE #1 Research Report, July 1997 and the accompanying highlights videotape.) The six priority areas identified by FBE #1 participants as those for ITI-ALC Phase II prototyping to address were:

- Sign-on and sign-off using smart cards with secure PIN numbers;
- IETMs and TO's with current data for specific aircraft;
- Communications/collaboration for interaction with engineers or remote experts;
- Electronic parts tracking, especially for back-shop coordination/status;
- Electronic support for unpredictables, for entering information and getting it quickly into PDM, and
- Inspection support for easy defect entry and communication for PDM action.

This initial formal usability event, and its findings, served as the key inputs for the initial prototyping effort.

4.2 Informal Data Collection Events

As noted earlier, two data collection efforts to WR-ALC and one to Tinker AFB followed to conduct additional research about the nature and relevance of these priority areas for the F-15 and other product lines within the USAF. First prototyping included examination of various hardware platforms, display capabilities and interface designs. In early November 1997, a second usability event occurred when the ITI-ALC Phase II team conducted an informal, small scale feedback session with E&I inspectors, skin mechanics, engineers, and avionics technicians at Robins AFB to elicit their reactions to early prototypes. (For a detailed account of this event, please see ITI-ALC Trip Report - Warner Robins AFB, November 5 & 6, 1997.)

The initial E&I Inspection prototype was implemented on a Newton 2000 and we checked handwriting recognition with both "printing" (block letters) and "cursive" options. Four E&I inspectors were individually walked through the initial prototype application and gave us feedback about legibility, response time, whether there was missing or unnecessary information on each screen, the weight/feel/size of the platform, etc. Major items we learned that were considered for the E&I prototype refinement included:

(1) the E&I process was undergoing change:
- we needed to allow for individual inspector preferences and possible use of rational criteria for the order and sequence of inspections,
- the stand alone system and clerk present at FBE #1 were gone,
- a direct connection to PDMSS was almost operational (i.e., triple entry of inspection information was becoming double entry and the ITI-ALC prototype could make it a single entry process),

(2) the defect list changed:
- with use by two new inspectors the list was reduced to 190, instead of 212 defects,
- an initial cut was made to specify the 48 worst defects (those that take longest to fix, need parts that are hard to get, have major impact on aircraft output dates) and was made available to the ITI-ALC team,

(3) the E&I and first line supervisors were working toward more complete 173's (with more fields pre-filled) for mechanics
- an initial example was provided for possible inclusion in ITI-ALC prototyping.

Prototypes to support the Collaboration and Operational Check scenarios derived from the initial user requirements both were implemented using a Fujitsu Point 510 portable platform with handwriting as the input medium. Again we sought user response related to the platform (weight, feel, how they would hold/use it), and asked about the same characteristics mentioned above. Two mechanics and two engineers had a very positive reaction to the Collaboration prototype. Specific feedback from the engineers included: (a) that the ITI-ALC prototype needed to work with their existing email systems (Microsoft Exchange) and (b) that they needed much better prioritization information (indicators of

which message to attend to first). The mechanics feedback included: (a) a concern that we get planners involved in feedback and their sign-off/role to be clearer in the application, (b) consider adding phone capability (for mechanics to call or be called by engineers), and (c) the light glare on the screen interfered seriously with legibility and use of this initial prototype. All of this feedback was considered in the changes and refinements made to prototypes during December 1997 through February 1998. Due to difficulties in obtaining needed technical documentation and other resource constraints associated with developing the Operational Check scenario, the ITI-ALC Phase II team prototyping effort was focused on the E&I Inspection and Engineering Assistance (Collaboration) prototypes as of January, 1998.

4.3 FBE #2 Formal Usability Study Event

For FBE #2, conducted in February and March 1998, two of the Robins AFB Evaluation and Inventory Inspectors participated in the study (two other inspectors were unable to participate due to extended absence from work for health problems). First, the overall results of the FBE #2 E&I inspection effort are summarized. Then, a detailed descriptive analysis of the errors, information needs, and physical interactions of the inspectors while trying out the prototype system is provided. Finally, the inspectors' preferences related to the prototype system are presented.

Similarly, we report the results of the Collaboration prototype evaluation that was tried out by six F-15 skin mechanics and one structural engineer.

4.3.1 FBE #2 Demographic Summary

The two E&I inspectors' demographic characteristics at the time of FBE #2 included: Participant 11 (P11) who had more than 32 years of aircraft maintenance experience and 8.5 years experience doing E&I inspections and Participant 14 (P14) who had 13 years of aircraft maintenance experience and just 9 months of experience doing E&I inspections. Their respective ages were 57 and 40 years. Both men had no prior experience with any kind of computer. Both men used corrective lens (P11 had bifocals and P14 was myopic) and each reported a problem with sensitivity to bright light.

Both participants did the E&I inspection of the cockpit (areas 2, 2A) and the engine compartments (area 12) without the prototype in February 1998 and with it in March 1998 and they identified several areas for improvement during the field usability evaluation.

The six mechanics in FBE #2 were Participants 4, 15, 17,18, 19, and 20. They had an average of 10.7 years experience doing aircraft skin repair work. Their average age was 40 years. Four of these participants had no prior experience using a computer, while two of them had moderate experience, having used a home PC to access the Internet, prepare documents with Microsoft Word, and for email.

Three of the skin mechanics had no eye correction (reported that they have 20/20 vision). Participant 4 wore corrective lenses for myopia and Participants 17 and 20 had bifocal correction.

The structural engineer, Participant 16, had more than 25 years of experience working with F-15s and he was 56 years old when FBE #2 was conducted. He reported that his experience using computers was "moderate" having done some programming and used a PC with Win95 and for email. He used eye correction for myopia and bifocals.

Each of the six individuals participated in the "without" and "with technology" trials of the prototypes in February and March of 1998. They also identified several areas for improvement, which are summarized in this report. Their inputs were used to modify the prototype for the shakedown and final evaluation efforts.

4.3.2 FBE #2 Errors, Failures, Requests for Information, and Physical Interactions

These category structures were created from the measurement needs (e.g. observing mispressed buttons for usability concerns) outlined in the FBE #2 demonstration plan (ITI-ALC Technical Report; Document #63A156465, Rev: New, 4 March 1998). Additional categories were added to cover other observed relevant behaviors (e.g. from watching the tapes it became clear that one important request for information was verification (e.g. "Am I going the right way?") so an explicit subcategory was created within "requests for information" for this.)

Tables are presented for each of these error categories to summarize the frequency of each phenomenon. The E&I task tables are organized by E&I participant (P11 or P14 for the) and task (cockpit or engine compartment inspection). Note that due to counterbalancing for this study, P11 did the cockpit first and the engine compartments second, while P14 did the engine compartment first and the cockpit second. Hence, any phenomena due to lack of practice will attenuate oppositely across the tasks for the participants. The participants organize the Collaboration task tables.

4.3.2.1 FBE #2 Categorization of Errors and Failures

Errors and failures were coded using the following categorization scheme:

- Any repeated button presses or check box taps (due to system not registering tap or linking problem)
- Handwriting recognition errors (e.g. Ben5 instead of Ben, etc.) Scrolling problems
- Hitting wrong key (e.g. hitting "edit" key instead of backspace on editing palette)
- Interface object interference (e.g. edit palette on top of exit button)
- Misinterpretation of what something means
- Slow to perceive or forgets needed information

- Finds information not pertaining to correct region of aircraft
- Wireless network failure
- Interface performance failure

The most common problems in this category for E&I inspection (Table 4.3.2.1-1) were repeating actions (11), noting electronic 173 cards in wrong region (11), tapping while scrolling (instead of just holding the arrow down) (7), and having problems with handwriting (6). The repeated action problem and the scrolling problem were very likely due to two sub-problems. First, the screen of the prototype client is highly sensitive to motion - it makes a distinction between a "tap" and a "drag." If a participant moved the pen on the screen while tapping a checkbox (e.g. by using a metaphor from paper and trying to actually check it or fill it in), the system would not register the tap. Secondly, the occasional slowness in response caused participants to sometimes believe that their valid taps had not registered. For the scrolling case, it is likely that a similar phenomenon arose - in this case, because the system was not immediately responsive, P11 may have developed a tapping strategy. In addition, he repeatedly tried to drag the arrow button, indicating that he did not quite understand how the scrolling panel operated.

Table 4.3.2.1-1 FBE # 2 E& I Inspection Task Frequency of Errors and Failures

Errors and Failures	P11		P14		Total		Total
	Cock-pit	Engine	Cock-pit	Engine	Cock-pit	Engine	
a) Repeated Actions	5	1	3	2	8	3	11
b) Handwriting	5	0	0	1	5	1	6
c) Scrolling	3	2	0	2	3	4	7
d) Wrong Key	3	0	0	0	3	0	3
e) Interference	0	0	1	0	1	0	1
f) Misinterpretation	0	0	2	0	2	0	2
g) Slow Perception	1	2	0	2	1	4	5
h) Region Problem	2	4	4	1	6	5	11
i) Network Failure	0	0	2	2	2	2	4
j) Interface Failure	0	0		1	0	1	1
Total	19	9	12	11	31	20	51

The most common problems experienced by the users of the Collaboration (Table 4.3.2.1-2), (Engineering Assistance) prototype were: difficulty with handwriting (14), difficulty remembering needed information (11), and hitting the wrong key or area of the interface (9). Individuals had difficulty with particular letters, e.g., "f" which lead them to need to erase and retry information entry. The Form 202A completion activities were affected by the same kind of handwriting problems noted above for the E&I inspection prototype.

Table 4.3.2.1-2 FBE # 2 Collaboration Task Frequency of Errors and Failures

Errors and Failures	P15	P17	P18	P19	P20	P4	Total	
a) Repeated Actions							3	3
b) Handwriting	2	6	2				4	14
c) Scrolling							1	1
d) Wrong Key			1	3	2	1	2	9
e) Interference								0
f) Misinterpretation								0
g) Slow Perception	2	4	2		2	0		10
h) Region Problem								0
i) Network Failure			1			1		2
j) Interface Failure				2	2		0	4
Total	4	12	9	4	4	10		43

4.3.2.2 FBE #2 Categorization of Requests for Information

The requests for information were coded using the following categorization scheme:

- Interface widget location information (e.g., Where is button X?)
- "How to" information (e.g., How to I get back to other region)
- General confusion (e.g., What do I do next? I don't know what to do here)
- Verification of information (e.g., "Is that right?" "Should I log on here?")
- Explanation of behavior of technology (e.g., "Why did it do that?")

The most common requests were for the E&I prototype (Table 4.3.2.2-1) were for: verification (15), "How to" information (12) and for explanation (11). The "how to" requests are for specific information on how to accomplish something (e.g. "how do I backspace?" "What do I do to get to the other region?"). Some of these actions were covered in training - the requests point to places where the interface does not make readily obvious how to accomplish the action (i.e. the interface is not "walk up and use" for that action). Verification of information serves a similar purpose - in these cases the participants have an idea of what to do (which may be right or wrong) but are not confidant enough to take the action without further reassurance. Asking for explanation is a case where the system is not making its behavior clear enough, e.g. P14 asks about the hourglass. This is a standard icon in Windows indicating the system is working on something so the user should wait. Even though P14 was exposed to this information during training, the hourglass image was not enough of a reminder.

Table 4.3.2.2-1 FBE # 2 E& I Task Frequency of Requests for Information

	P11		P14		Total		
Requests for Information							
a) Location	2	0	0	1	2	1	3
b) "How To"	7	0	2	3	9	3	12
c) General	3	3	2	3	5	6	11
d) Verification	3	6	5	1	8	7	15
e) Explanation	2	1	0	5	2	6	8
Total	17	10	9	13	26	23	49

The most common requests for the Collaboration prototype (Table 4.3.2.2-2) users were: for verification (27), "how to" information (16), and general confusion (14), e.g., being unsure about leaving fields in the form blank or about how to use the camera. There were a few instances of asking for an explanation (5), e.g., asking whether the aircraft will block/interfere with the wireless connection or asking whether a field is big enough to handle an entry. Users of this prototype made no requests for locational information.

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Table 4.3.2.2-2 FBE # 2 Collaboration Task Frequency of Requests for Information

Requests for Information

a) Location							0
b) "How To"	3	4	4	1	2	2	16
c) General	1	1	5	1	4	2	14
d) Verification	3	8	7	4	3	2	27
e) Explanation		2	2		1		5
Total	7	15	18	6	10	6	62

4.3.2.3 FBE #2 Categorization of Physical interactions

The physical interactions were coded using the following categorization scheme:

- Any adjustments or accommodations made while wearing the Fujitsu 1200
- Moving 1200 out of way (but keeping on body)
- Taking unit off
- Comments relating to this: e.g. "This feels kind of awkward"
- Stowing pen when 1200 not in active use
- Hand cleaning required before using device
- Effects of being left/right-handed on use of system

The most common E&I prototype (Table 4.3.2.3-1) physical interaction issues were: the need to adjust the system (5), removing the unit (3), and commenting on the system getting in the way (2). P11 clearly had a problem with the form factor and support structure for the system. During the cockpit inspection he took the unit off for substantial periods of time, and commented once when he had it on that it was awkward. This was during an inspection under the dashboard in the forward cockpit where he had to hold the Fujitsu 1200 out of the way with one hand while holding a flashlight with the other. His strategy of interleaving the inspection task with using the system appeared to make it especially hard for him. After doing a short piece of the inspection he had to pick up the device and use it, and then let it hang down, move it to the side or take it off for the next part of the inspection. He had similar problem in the engine compartment inspection. P14 seemed to have less of a problem, but still had a problem. No explicit interaction problems were observed where he had to take off the unit or move it out of the way while in the cockpit, though he did comment that he thought it was going to get in the way. There were two times during the engine compartment inspection that he had to adjust the system. His easier time may be due to his strategy of doing the entire inspection first while having the unit hanging down, and then using the system in one block when he finished the inspection. Also, because he was a smaller individual he might be able to accommodate the form factor more easily. The preference data described in the next section address participants' concerns on the form factor as well.

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Table 4.3.2.3-1 FBE # 2 E& I Task Frequency of Physical Interaction Problems

	P11		P14		Total		
Physical							
a) Adjustment	1	2	0	2	1	4	5
b) Removing Unit	3	0	0	0	3	0	3
c) Comments	1	0	1	0	2	0	2
d) Stowing Pen	0	1	0	0	0	1	1
e) Hand Cleaning	0	1	0	0	0	1	1
f) Left/Right Hand	0	1	0	0	0	1	1
Total	5	5	1	2	6	7	13

Overall there were not many issues (9) raised about physical interaction issues for the Collaboration prototype (Table 4.3.2.3-2). The most common physical interaction issues were related to taking pictures (4) where users dropped the pen while using the camera or had shaking hands while trying to control the camera in mid-air. Three instances occurred where users had difficulty with screen glare. Additionally, one participant had difficulty stowing the pen, and another participant had trouble with the strap getting in his way while trying to move the pen. The results of the behavioral coding described here are summarized in the next section.

Table 4.3.2.3-2 FBE # 2 Collaboration Task Frequency of Physical Interaction Problems

Physical						
a) Adjustment			1			1
b) Removing Unit						0
c) Comments		2	1			3
d) Stowing Pen		1				1
e) Hand Cleaning						0
f) Left/Right Hand						0
g) Taking picture		1	1	1	1	4
Total	0	1	4	3	1	0	9

4.3.3 FBE # 2 Preference Data

Both the pros and cons of participants' experience in evaluating the prototypes are provided here. The inspector's post-questionnaires are presented first. These results suggest that they are positive about the use of the prototype system. This is followed by a summary of the post-trial interview and debriefing feedback received by the ITI-ALC team. Then, material from the questionnaires and interviews is summarized for the skin mechanics regarding their feedback on the Collaboration system.

4.3.3.1 FBE # 2 E&I Inspection Prototype Feedback

When asked what they liked best, P11 noted, "It was fairly easy to use, but somewhat difficult when making a new write-up. P14 stated that mobile system "saves time, gets information to other organizations much quicker, and saves on paperwork." Both men noted that the defects from their master listing were in the system and they did not specify any additional information they need to do their tasks with this prototype.

When asked what they liked least about using the mobile prototype, P11 said "somewhat difficult when making a new write-up" while P14 said he "worries about dropping or bumping the unit during inspections. Changes the inspectors would like to see in the near future include: P11: bigger screen, fewer handwriting recognition errors, and more training time, and P14: faster response time, ability to partially change defect descriptions, and more protection around the unit. Comparing use of the prototype to doing this task using paper, the inspectors had very different reactions. P11 stated that "it (the prototype) slowed me up approximately 25% of normal time by not being used to it." P14 said, "Great; I think this will be a great asset to the Air Force."

P11 indicated that he could see the text and graphics in the application and find the information needed for the E&I inspection very easily. P14 also rated seeing text as very easy, but he did not express an opinion about graphics and he ranked finding the information he needs for an E&I inspection as a "3" on a 5-point scale where "1" means "very easy" and "5" means "very difficult."

When asked on the questionnaires about anything else to share with the ITI-ALC team about their experience with the mobile prototype, P11 said "I would like more meeting sessions with evaluators and computer. P14's response was "I know nothing about computers, but this unit was easy to learn and it seems to me it can do many things, I just have to learn how to operate it."

During interviews, inspectors rated the physical prototype (Fujitsu 1200) and the application running on it as follows:

Attributes:	P11	P14
Computer weight:	"O.K."	"Lighter than expected"
Seeing information on screen	"very clear"	"very clear"

Using the pen to write on the computer	"difficult"	"difficult"
Correcting handwriting mistakes	"difficult"	"O.K."

Additional remarks, which add to the information that the inspectors shared on their questionnaires, are summarized here. P11 noted that right now paper would be better for writing new cards, and said if they hadn't used the computer for writing new cards then it (the computer) would probably be better than paper. P14 commented that he hoped technicians would be offered the opportunity to receive some schooling to learn how to use mobile tools. Both inspectors noted that there was some defect to area mappings that didn't pertain to the areas they inspected. Their input on this matter was recorded immediately after the debriefing sessions.

4.3.3.2 FBE # 2 Collaboration (Engineering Assistance) Prototype Feedback

Participants indicated that what they liked most was having the information "at your fingertips", getting information and answers faster, and getting away from using paper. What they liked least was handwriting on the screen, size of the mobile computer, and presence of too many cords. Participant 15 indicated a need for TO's that were not available to him while doing the vertical tail assembly task. (Please note that there were five responses reported in this section of the report because Participant 4 did not complete the post-task activities due to time constraints in the data collection effort for FBE #2.)

Participant ratings indicated that they found it very easy to find information needed for Form 202A completion. All participants except Participant 18 also found it very easy to see textual material while using the prototype. Three participants indicated that seeing graphic information while using the prototype was very easy, while two participants indicated that it was difficult. (Note that one of these participants did not have corrective lenses while the other participant is nearsighted and wears bifocals.)

When asked what they would change to improve the prototypes, three skin mechanics stated that they would improve the handwriting recognition/reduce the number of errors for future prototypes and one participant indicated that having larger letters on the pop-up keyboard would be helpful. One participant also mentioned that having a smaller unit would be preferred. Two participants indicated that they would not change any features of the prototype as of FBE #2.

All five participants made positive statements about their feelings using the mobile computer instead of paper to do their tasks. Three of these five mechanics did state that they felt slightly awkward at first but that they felt that with practice they could become quite comfortable using such a prototype. One of the mechanics stated, "It was excellent. Mechanic has too much paper work already" (P15).

4.4 Shakedown Event

The Shakedown event followed in the cycle of iterative development. Many of the system and interface challenges that surfaced during FBE #2 were addressed successfully by the ITI-ALC Phase II team. The team also prepared and delivered very successful training that resulted in the incidence of errors and failures, requests for information, and physical problems to be dramatically reduced.

4.4.1 Shakedown Preference Data

The four participants completed the same post-trial questionnaire as the one used in FBE #2. Overall their responses were very positive regarding their use of the prototype. These completed questionnaires are included in Appendix D.

Their rankings of ease of seeing and finding information were all "1" or "2" on the scale of 1 to 5 with "1" being "very easy" and "5" being very difficult, with one exception. Participant 2 ranked seeing the graphic representation of the aircraft as a "5" for the Collaboration task.

All participants made suggestions for changes and improvements for the prototypes that mentioned the pen and its sensitivity and they suggested developers should try to reduce its sensitivity. Participants 2 and 4 both mentioned faster response times as desirable. Participant 1 suggested that a smaller unit might be helpful for inspection tasks or tasks in tight spots. Participant 2 commented on the tediousness associated with continuous use of the pen. Participant 3 suggested that a larger screen would help or that it would be useful to enable technicians to adjust the size of the field(s) they are currently using. Also Participant 3 noted that the mechanic should get some concrete feedback about the voice and picture attachments before sending the Form 202 A to the engineer. Participant 3 also commented about the bungee cord for the pen wrapping around the device. Participant 4 noted that the prototype should "find a way to let technician know if they were about to exit without submitting defects recorded during that session".

Comparing use of the prototype to using paper for these tasks, all participants strongly preferred the prototype. Though one (P2) expressed concern about having a very reliable system. Their overall comments about the experience were very positive. P1 stated, "I enjoyed taking part in this testing of the mobile system. I found it very simple and very useful and hope to use this system in the future." P2 commented, "It was fun, I enjoyed it, a good system." P3 stated, "Much easier and handier than utilizing the 3 or 4 items that this unit replaces." Finally, P4 commented, "Loved it. I found it very useful as a guide of how to perform E&I inspections. For non-experienced inspectors, this would be a great tool

4.5 Final Field Trial

RESULTS

Materials used to collect data included the questionnaire, interviews, observations (Appendix E) and screen walkthroughs (Appendix F). Appendix E presents each questionnaire item, the responses (in a graph), comments by the participants (in *italic bold*), and test administrator observations [identified in brackets]. Appendix F represents the screen walkthrough participants. These walkthroughs are divided into three applications: inspectors, mechanics, and engineers. Again, participant comments are in *italic bold* and test administrator observations are [identified in brackets].

DISCUSSION

The purpose of this field test was to achieve the goals listed below. In order to achieve these goals within the constraints of the project, data collection was completed using four techniques. This Discussion section is organized in accordance with the project goals and uses data presented in the Results section to address each of those goals.

Project Goals

        Goal 1. Validate the concept of an ITI-ALC system

        Goal 2. Evaluate the ITI-ALC system in its ability to address the Business Process Improvements identified from Phase I activities (i.e., its ability to lower operating costs)

        Goal 3. Evaluate the ability of an ITI-ALC system to improve job performance

        Goal 4. Identify specific improvements that can be made to the hardware and software for future ITI-ALC system implementation programs.

        Goal 5. Provide lessons learned for development of an ITI-ALC system.

Goal 1. ITI-ALC Concept Validation

Participants validated the ITI-ALC concept in several ways. They indicated that this system would increase access to information and that with practice and computer experience, novices could use it easily. In addition, technicians indicated that, depending on the task at hand; they would use the system for their primary job. They also indicated that they would use an ITI-ALC system fairly frequently if provided.

Participants stated that this system would be useful in numerous maintenance areas, including "all depot maintenance on aircraft" and "part numbers, repairs, general information-TOs." Maintenance areas where they did not think it would be useful included "tight areas."

Goal 2. Ability to Address the Business Process Improvements

Five Business Process Improvements (BPIs) were addressed through data collection activities during the ITI-ALC field test. For specific information concerning the full implication of each BPI refer to the Architecture Report (Systems Research and Application Corporation, 1995).

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BPI 8. Electronic Signatures

Participants felt the I-button (electronic signature emulator) was faster and more secure than the current signature process (Job Performance questions 8 & 9). It was observed that the I-button was easy to disconnect and therefore frequently fell off. To implement the I-button, modifications would need to be made to minimize loss of the I-button due to inadvertent disconnections.

BPI 9. Performance Metrics Based on Actual Data

Reactions varied concerning the accuracy of estimates of time to complete. Overall, participants did not indicate that they thought it would increase accuracy over other methods.

BPI 10. User Technical Information Presentation System

Participants indicated that they thought the ITI-ALC system would increase use of TO data, yet not for all tasks (ITI-ALC Concept question 1)

BPI 13. Automated and Integrated Technical and Diagnostics Information

In comparison with the current process, participants felt that ordering parts would be faster and easier with an ITI-ALC system (Job Performance question 4). Overall, they felt an ITI-ALC system would increase access to technical information (ITI-ALC Concept question 2).

BPI 14. Multi-skilled Mechanics

Participants felt that use of an ITI-ALC system would be easy (yes) or possible (maybe) for a novice technician (ITI-ALC Concept question 5). When asked about performing tasks outside their specialty, reactions were more hesitant (ITI-ALC Concept question 6). Responses indicated that they thought it was moderately possible.

Goal 3. Perceived Effect on Job Performance

In comparison to the current TO system, the ITI-ALC system was perceived to be both faster and easier along several dimensions. These dimensions include information retrieval, form retrieval, part ordering, and other information access.

The main concern in comparison with paper is that searching a paper TO is a fairly straightforward task (thumb through it). The ITI-ALC system's current search strategies (organization of the TO data) and TO data access capabilities need improvement. TO data should be organized according to aircraft location, technician specialty, and a numeric sequence—preferably all three of these. For example, once the user logs in TO data would be primarily available for that technician's specialty. The technician could limit searching based on the aircraft location currently being worked (through graphical selection of location). Finally, TOs could be organized according to numeric sequence. Currently TOs are organized alphabetically; therefore an alphanumeric search strategy is not an uncommon concept to the end-user population.

Goal 4. Specific System Improvements for Hardware and Software

Discussion of system improvements is organized according to two main categories. Most of these categories are related to the software and user interface while the remaining are related more specifically to the hardware.

Software and User Interface

Several topics concerning the ITI-ALC user interface were evaluated. These topics included accessing information, entering information, viewing information, submitting information, and navigating among screens. Each of these will be discussed.

Access to information using the ITI-ALC system was perceived for the most part as faster and easier than current methods. When the system was busy working, indicators were obvious to participants (i.e., the hour-glass icon adequate relayed that the CPU was busy).

Information entered into the ITI-ALC system was identified as easy to read (i.e., font size was sufficient) and was generally perceived as taking less time than the current method of data entry. Entering information via the on-screen keyboard was identified as primarily easy. Participants rated highly the selection of part numbers through picture selection—the main critique was that they wanted to use this method to select multiple parts. Use of the pen-based system to sketch and draw information was perceived as moderately easy; however, these responses were slightly less positive. These were probably due to difficulties using the pen.

The pen posed many problems in entering and selecting information. While handwriting recognition was generally good, participants had repeated problems selecting icons, menu items, and other screen widgets. These tasks were accomplished by "tapping" or "double-tapping" on the desired item with the pen, much like a "click" or "double-click" is used with a mouse. Many comments concerned the sensitivity of the pen. Perceived sensitivity can be defined as length of the tap, pressure of the tap, and angle of the pen during the tap. Clearly, this is an area that requires improvement before a pen-based system can be effectively implemented in the field.

Again for viewing information, participant felt that information was easy to read—only the engineers exhibited any difficulty, and this problem could be readily eliminated with the standard-issue of 17" monitors. Information presented on the screens was perceived as adequate for accomplishing the task and perceived as the same or easier to read than paper.

Overall, participants felt that submitting information was easy, as was understanding, when the system was sending data. Participants also indicated that the ITI-ALC system took less time to submit information than the current method. However, initiation of a submission was problematic for inspectors. The icons located at the top left of the screen (stamp, envelope and +) caused several problems in submitting information. Specifically, icons in the right menu bar were confused with those at the top, which caused several user errors to occur.

While right menu bar navigation was perceived as easy to understand, screen navigation for the inspectors was problematic. This problem was compounded by the errors made submitting information via the top left icons. One example in particular is upon sending the defects the system navigates back to the 173 Task List. This automatic navigation was "too far back" and confusing to the user.

System Hardware

While the ITI-ALC system was perceived as comfortable to wear, technicians indicated that they were "worried about banging it up" and that they "would take it off before performing maintenance inspection." These comments are in accordance with their reactions that the system interfered with the task in some cases and that is was only moderately convenient while performing the task.

Straps were perceived as keeping the system securely fastened, although one (thin) technician had some difficulty keeping the computer from sliding down into a perpendicular position to the ground.

Comments and question responses to the pen have been discussed in the previous section; however, it should be noted again that "tapping and touching caused problems" and that the sensitivity of pen needs adjustment.

Reviewing, selecting, and saving photos were perceived as fairly easy. Additionally, engineers indicated that the digital camera would decrease the number of trips to aircraft. However, several aspects of this device require improvement. The digital camera provided adequate detail in some cases; yet, many of the images were out of focus or did not provide enough detail. This indicates that improvements need to be made in image quality. While sheet metal mechanics did try to capture in-focus images, this was not an easy task. A lag in the camera's refresh processing capability caused further problems. As the camera was pointed at an area of interest, any slight movement would cause an additional capture. However, the refresh rate on the computer lagged behind in relation to the image capture, resulting in a display image that was not always immediately representative of the most recently captured image.

Recording, playing back, and reviewing voice notes were perceived as easy to use in almost all cases. The only concern involved potential interference from background noise (indicating the potential need for filtering), yet engineers did not have difficulty understanding the voice notes attached to the 202A forms generated during the test.

Goal 5. Lessons Learned from Applications

Lessons learned are captured in the discussion of each of the goals of this field test.

5. *Conclusions*

Lessons learned from the ITI-ALC Phase II efforts are provided below and are grouped by categories developed by the team.

5.1 Domain

- Understanding tasks of users in detail is essential to appropriate applications design
- Processes for PDM appear generalizable from one product line to another (same system should work with minor modifications for F-15, C-130, C-141, etc.)
- Enabling linking to multiple information sources plus human to human interaction only needed occasionally
- Intelligent searching of past work would be helpful addition in the future.

5.2 Technical

- Handwriting recognition needs to be improved - use of a better recognition package may be essential to technician acceptance of system. This is an area that is receiving increased attention as 'palm-top' computing becomes more widely used, and it is reasonable to expect that better packages will soon be available.
- Wireless coverage and stability may be a challenge in the hangar environment due to multipath interference that results from the metal enclosure and the metal aircraft therein. Permanently mounting antennae at elevated positions on the wall may ameliorate this.
- Camera cord design - we should design and implement a camera cord restraint system that doesn't interfere with use of the system when stowed and has sufficient flexibility to adjust to different heights/arm lengths of users

5.3 User environment

- Lighting glare and variable lighting in the hangars require back lighting and active matrix displays on the mobile computers
- Replacement of the mobile platforms with hardened units or improved cases to prevent damage from dropping/hitting hard surfaces should be considered
- Allowing for flexible/individual variations, the work processes (especially E&I inspection) are more viable with prototypes
- Overall user enthusiasm at Robins AFB for changing/improving work processes facilitated developers' effort

- Management support for improving work processes and trying out new technology a real plus for ITI-ALC Phase II team.

5.4 Commercial Off the Shelf (COTS) Technology

- Smaller, lighter mobile computing platforms are required for extended use
- Lithium ion batteries provide longer operation per charge, more charge/discharge cycles before replacing battery
- Pentium 120 MHz mobile platforms provided plenty of computing power for thin client
- The low-cost, light weight digital ViCam can be made to work adequately with careful use, but an autofocus camera would provide more uniform results
- The iButton reader is a cheap, reliable electronic identification solution that the users accept and have confidence in
- Turnkey applications for non-computer users should not be built on Windows 95; the operating system lacks both desirable security features and reliability
- Internet Explorer 4.x allows the underlying web application implementation to be concealed (through its "full page' feature), but its failure to use standard Windows widgets on web pages reduces its compatibility with other COTS products
- Currently available voice recognition software can effectively support either voice navigation or voice dictation, but not both
- Voice navigation software does not currently work well with web applications
- RF LAN networks, like wired networks, really achieve only 50% or less of the vendor's claimed bandwidth
- RF LAN networks suffer from reduced bandwidth when used near operating microwave ovens
- RF LAN network bandwidth is reduced by multipath interference inside metal hangars
- RF LAN access points should be positioned such that their coverage area overlap is minimal to prevent mobile units from 'hunting' for the best reception (and sometimes missing transmissions as a result)

5.5 Integrated Product Team (IPT) Structure

- Management of multiple, geographically distributed subcontractors consumes enormous amounts of program resources unless each subcontractor has clearly defined products to be delivered
- Contractors should have frequent contact with Lab management
- Experienced Lab representatives should participate in each IPT so that their experience and expertise can guide the contractor toward the Lab's desired goals

6. References

Systems Research and Applications Corporation, (1996). Business Case for Integrated Technical Information for the Air Logistics Centers (ITI-ALC), AFRL-HE-WP-TR-2002-0058, Wright-Patterson AFB, OH: Air Force Research Laboratory, Logistics Readiness Branch.

Systems Research and Applications Corporation, (1996). Integrated Technical Information for the Air Logistics Centers (ITI-ALC) Phase I Final Report, AFRL-HE-WP-TR-2002-0059, Wright-Patterson AFB, OH: Air Force Research Laboratory, Logistics Readiness Branch.

7. *ACRONYMS AND ABBREVIATIONS*

This section lists the acronyms and/or abbreviations used in this document.

Acronym Abbreviation	Definition
A/C	Aircraft
AFMC	Air Force Materiel Command
AFRL	Air Force Research Laboratory
AFTO	Air Force Technical Order
ALC	Air Logistics Center
AREP	Aircraft Repair Enhancement Program
BPI	Business Process Improvement
CAMS	Core Automated Maintenance Improvement
CDRL	Contract Data Requirements List
CIC	Communications Intelligence Corporation
CMU	Carnegie Mellon University
COTS	Commercial-off-the-Shelf
CSC	Computer Software Component
D-level	Depot level
DoD	Department of Defense
E&I	Evaluation and Inventory
FBE	Field Based Evaluation
FEMS	Facility Equipment Management System
FIPS	Federal Information Processing Standards
FOD	Foreign Object Damage
HESR	Logistics Readiness Branch
HTML	HyperText Markup Language
ID	Identification
I/F	Interface
I-level	Intermediate level
IMDS	Integrated Maintenance Data System

IMIS	Integrated Maintenance Information System
I/O	Input/Output
IPDF	Indexed Portable Document Format
ITI-ALC	Integrated Technical Information for the Air Logistics Centers
LAN	Local Area Network
LM ATL	Lockheed Martin Advanced Technology Laboratory
LMIS	Lockheed Martin Information Systems
MHz	MegaHertz
O-level	Organizational level
PDM	Programmed Depot Maintenance
PDMSS	Programmed Depot Maintenance Scheduling System
RAFB	Robins Air Force Base
REQ	Requirement
RF	Radio Frequency
SEI	Software Engineering Institute
SOW	Statement of Work
SSR	Software Specification Review
SSDD	System/Segment Design Document
SSS	System/Segment Specification
SW	Software
TFT	Thin-Film Transistor
TO	Technical Order
WPAFB	Wright-Patterson Air Force Base
WR-ALC	Warner Robins-Air Logistics Center

APPENDIX A

TRADE STUDIES

Appendix A: Trade Studies

A-1. Collaboration Trade Study

1.0 Summation

1.1 Purpose

The purpose of the collaboration trade study is to investigate collaborative software systems that enable communication between individuals who are not co-located. This communication takes several forms: audio, video image transmission, sharing a common whiteboard, and sharing applications. The intent is to use the collaboration software to enable a technician working at an aircraft to discuss a problem and its solution with an engineer at her desk in a remote building. Audio will be used to discuss the problem; video to share a picture of the problem; application sharing to view and control electronic technical manuals; and shared whiteboarding to illustrate ideas on both the pictures and manuals.

1.2 Products

We evaluated the following products in this trade study:

Company	Product Name
Intel	Internet Video Phone 2.0 with Proshare Technology
Microsoft	NetMeeting 2.0
VocalTec	InternetPhone 5.0 with Video
WhitePine	CUSeeMe 3.0

These products are all software-only solutions. They require no proprietary hardware such as video capture and compression boards. By making this decision to evaluate software-only solutions, we allow the ITI-ALC project to pursue high quality audio and video solutions independent of collaboration systems. In addition, this decision allows the ITI-ALC project to pursue audio and video hardware specifically tailored for each delivery platform.

1.3 Environment

The four products were tested in an environment that closely simulates what we expect to encounter in the ITI-ALC project. One test computer simulated a technician's wearable computer. This computer was Carnegie Mellon University's (CMU) Tactical Information Assistant Prototype (TIA-P). The TIA-P was built around an Epson Cardio card containing an Intel 486-75 Mhz processor and 16 MB of RAM. In addition, the TIA-P was equipped with an Aironet ARLAN 690 two Mbps wireless ethernet adapter. A Connectix Quickcam was used for video capture, and a Knowles VR-3185 headset was used for audio capture. The TIA-P was running Windows 95.

The second test computer simulated an engineer's desktop workstation. This computer was a dual boot Windows 95/NT 4.0 workstation, containing an Intel Pentium-133 Mhz processor and 32 MB of

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RAM. It was directly connected to CMU's intranet. An Aironet ARLAN ethernet access point was connected to the intranet to supply connectivity between the TIA-P and the workstation.

Of the four products, three ran on both Windows NT 4.0 and Windows 95 platforms. Intel's Internet Video Phone only ran under Windows 95.

1.4 Summary of Best Candidate

While none of the products is ideal, of the four products analyzed, Microsoft NetMeeting was deemed preferable: it has the best transmission quality for both audio and video, allows sharing of applications, and subscribes to both the International Telecommunication Union (ITU) H.323 audio/video standards and the ITU T.120 whiteboard standards. Its richness of features may overwhelm novice users, but NetMeeting's interface will be familiar to users of Microsoft's Internet Explorer. A stable, commercial company backs NetMeeting. Additionally, NetMeeting is the only product we evaluated that exposed any functionality via an application programming interface (API). This API, in the form of an ActiveX control, allows advanced scripting of the product, close integration of the product with the World Wide Web, and even modification of the user interface. NetMeeting brings together more collaborative tools, of solid and dependable quality, than any other single product on the market.

It is interesting to note that the September, 1997 issue of Byte magazine also reviews Internet based collaboration products in the article, "Lab Report: Software: See and Be Seen Over IP" (Seachrist, David; p. 104). Byte selects NetMeeting and WhitePine's CUSeeMe as the two leading products.

1.5 Evaluation of Other Products/Tools

Of the remaining three products, only WhitePine's CUSeeMe also provides adequate tools for the desired functionality. While there were sometimes significant disparities and delays in audio and video transmission, audio quality was very good, and video transmission quality was acceptable. Whiteboard technology is supported. In fact, both CUSeeMe and NetMeeting rely on Databeam's FarSite whiteboarding technology. Therefore, it is difficult to differentiate the two products based on their whiteboards – although we had difficulty setting up and starting CUSeeMe's whiteboard.

VocalTec's InternetPhone suffered from extremely poor quality audio and video transmissions. Large portions of spoken phrases never made it from the wearable machine to the desktop speakers. Video resolution was good, but the frame rate displayed on the desktop was quite poor, sometimes taking almost two seconds to register a change. Further, even when the full audio message got through, there could be as much as a five second lag between video and audio reception for the desktop machine.

Intel's Internet Video Phone was totally unacceptable by almost all measurements. Audio transmissions were incomprehensible. The video features would not work at all with a black and white camera, so we were unable to rate video transmissions. There was no ability to share applications or whiteboards. This technology is in beta, and might become more acceptable in the future, but is unusable for now.

1.6 Future Considerations

The internet collaboration market is very dynamic. It is worthwhile to keep track of the state of the products available, since the current leading products and the condition and responsiveness of their producing companies have the potential for swift change.

Of particular interest is PictureTel's product line. They offer two software-only products, LiveShare Plus and LiveTalk that support application sharing, whiteboarding, and audio communication. Given their experience in this arena, these products should be evaluated against NetMeeting. PictureTel's video conferencing systems all require proprietary hardware. While proprietary video capture hardware may be difficult to use in conjunction with a handheld computer, PictureTel's support of ITU's H.323 standard would allow ITI-ALC to use the PictureTel product at the engineer's workstation. ITU's H.323 standard would allow PictureTel's video product to interoperate with NetMeeting running on a technician's handheld computer.

As stated earlier, DataBeam's Farsite whiteboarding technology is an established sector leader and could be pursued if only a whiteboarding tool was needed.

The ITI-ALC project is now placing less emphasis on live video and more on high-resolution digital picture stills. It may be appropriate to place future focus on those collaboration products, which support superior whiteboarding, audio, and application sharing as opposed to products, which embody all collaborative technologies.

2.0 Trade Study Information

The products were sequentially installed and evaluated. All products were easily installed. However, as noted before, CUSeeMe could not locate where on the wearable computer it had installed its whiteboard. Generally, collaborative communication was initiated from the TIA-P test computer. Both audio and video were transmitted from the TIA-P to the workstation. The quality of the audio and video received at the workstation was then appraised. Prior experience with audio and video software products (in particular, the products being tested) has shown that the direction of transmission (TIA-P to workstation vs. workstation to TIA-P) does not affect the quality of the audio and video.

A test chart was used to help evaluate the quality of the transmitted video. None of the products transmitted the chart in a size and resolution sufficient to read the chart's numerical measurement system. However, it was clear that the NetMeeting transmitted video had both the highest resolution and best gray-scale differentiation.

3.0 Trade Study Assessment Tables

The NetMeeting (Table A-1-1) final score (1506) was appreciably higher (15%) than the CUSeeMe (Table A-1-2) final score (1309). The following list summarizes the key differentiating criteria:

Quality of video. NetMeeting's video frame rate was consistently two to three times higher than CUSeeMe's frame rate.

Timeliness of audio and video. NetMeeting's audio arrived significantly sooner than CUSeeMe's audio (two seconds vs. five seconds) with no noticeable loss in quality. As a result, NetMeeting's audio and video were substantially more synchronized upon reception at the remote workstation.

Application Sharing. NetMeeting supported application sharing and collaboration; CUSeeMe did not.

Application Programming Interface. NetMeeting exposed significant functionality via an ActiveX control.

For example, an included script allowed a NetMeeting conference to be launched and managed from a web page. While CUSeeMe could also be easily started, it offered no finer-grained method of application control such as starting and stopping video and adding and removing users.

<u>Cost.</u> NetMeeting was free. CUSeeMe was $70, with no support for application sharing.

Two products, VocalTec InternetPhone (Table A-1-3) and Intel Internet Video Phone (Table A-1-4), were primarily chosen as audio/video comparison points. When their audio and video proved to be of inferior quality, their trade studies were curtailed.

Table A-1-1 Microsoft NetMeeting 2.0					
Criteria	Rqmts	Weight	Score	Total	Comments
1.0 Performance					Quality and timeliness criteria are highly related and can't be judged independently of one another. A gain in one area will cause degradation in another. An ideal tool will find the best balance amongst the criteria for the available network bandwidth.
Quality of Audio - Is the audio understandable? Does the audio breakup, or is the audio distorted, to the point of being incomprehensible?		10	7	70	*Audio quality good. Occasional rasping or static.*
Timeliness of Audio - Does the audio arrive within two seconds? Faster is highly desirable		8	8	64	Quality of audio should be understandable at 1 sec delay, near perfect at 2 sec delay. *About 2 second delay.*
Quality of Video - Resolution For general use needed to establish context, 160x120 (pixels) is a minimum. For detailed shots, 320x240 is a minimum, while 640x480 is preferred and may be necessary depending upon the task.		10	7	70	*320x240 resolution possible.*
Quality of Video - Frame Rate For general use needed to establish context, 5 frames per second is a minimum. For detailed shots, slower frame rates are acceptable, but this is task dependent.		9	7	63	*2-3 frames per second. Note that none of the products achieved 5 frames per second – this score became a relative score, comparing this criterium across all products.*

Table A-1-1 Microsoft NetMeeting 2.0 (Continued)

Quality of Video - Color Depth For black and white cameras, 64 shades of gray need to be supported. For color cameras, 256 colors need to be supported.		6	10	60	*64 shades of gray.*
Timeliness of Video Video frames should be delayed less than two seconds.		5	7	35	Previous video frames help to mitigate video frame delays. *Delay of about 1 second.*
Ease of Use Minimize cognitive load Minimize possibility of error		10	7	70	*Feature heavy for our application. Easy to use tabbed dialog box. Potential for ActiveX interface.*
Learnability The system should essentially be "walk up and use" for the end-users. A maximum of 5 minutes training to operate the system effectively.		10	6	60	*Complexity leads to steeper learning curve, greater potential for confusion.*
2.0 Reliability					
Not Applicable					
3.0 Maintainability					
Not Applicable					
4.0 Producibility					
Not Applicable					
5.0 Capability					
Shared Application View		5	10	50	Can users view a common app?
Shared Application Control		5	10	50	Can users control a common app?

Multiple Shared Application Participants		4	10	40	Can more than two users share an app?
Sharing Technology Multicast (excellent), reflector (good), star topology (okay)		4	5	20	Which technology is used to allow multiple shared application and/or whiteboard and/or audio/video participants? *Star topology.*
Integratable Whiteboard Tool		6	0	0	Can the whiteboard tool be directly integrated into other applications?
Image Capture to Whiteboard		6	6	36	Can video images be captured directly to the whiteboard? Via cut and paste.
Multiple Whiteboard Participants		4	9	36	Can more than two users access whiteboard simultaneously?
Whiteboard Standards Adherence to International Telecommunication Union (ITU) T.120		5	10	50	Will the whiteboard tool interoperate with other products?
Bandwidth Adaptable Can the collaboration software be optimized for bandwidth available on a wireless LAN communication (1-2mb/sec)		7	8	56	Can the collaboration software adapt to available bandwidth?
Ability to Alter Audio Quality		6	3	18	This criterion and the next three deal with the ability to trade-off bandwidth resources
Ability to Alter Audio Timeliness		6	2	12	
Ability to Alter Video Quality		6	8	48	
Ability to Alter Video Timeliness		6	8	48	
Audio/Video Synchronization The closer the audio and video are kept synchronized, the better. A goal of 0.5 seconds is desirable.		8	8	64	Is the audio and video kept in synchronization? *No more than 0.5 seconds delay*

Table A-1-1 Microsoft NetMeeting 2.0 (Continued)					
Multiple Audio/Video Participants		8	0	0	Can more than two users videoconference simultaneously?
Audio/Video Standards – Adherence to ITU H.323		5	10	50	Will the videoconferencing tool interoperate with other products?
Image Capture Can a bitmap (.BMP), GIF, or JPEG image be captured?		6	5	30	Can an image (video still) be captured and output? *Via cut and paste.*
Dynamically Enable/Disable Audio/Video		9	0	0	Can the videoconferencing tool release the audio/video drivers so that other audio/video tools can access those resources?
Dynamically Control Audio/Video Quality and Timeliness Tradeoffs		8	6	48	Can quality and timeliness tradeoffs be made on-the-fly?
Can the Video Picture be Zoomed? (zoom in/zoom out)		8	5	40	
Change Microphone Capture Mode		8	0	0	Can the microphone be set to 'open', 'push to talk', or 'voice activated'?
Initiate and Control Collaboration Session		9	10	90	Can a collaboration session be fully started without keyboard input (e.g., via scripts)?
API to Capture Images		6	0	0	
API to Manipulate Video Window		6	6	36	
Independent Video Window		6	10	60	Is the video window independent of other collaboration windows?
Add/Remove Audio/Video Codecs		4	6	24	Can additional compression components be added at a later date?
Filter Out Ambient Audio Noise (echo cancellation)		4	7	28	Can the software filter out noise?
Cost per Seat less than $100		8	10	80	*Free*
		Total:	216	1506	

Table A-1-2 WhitePine CUSeeMe 3.0					
Criteria	Rqmts	Weight	Score	Total	Comments
1.0 Performance					Quality and timeliness criteria are highly related and can't be judged independently of one another. A gain in one area will cause degradation in another. An ideal tool will find the best balance amongst the criteria for the available network bandwidth.
Quality of Audio - Is the audio understandable? Does the audio breakup, or is the audio distorted, to the point of being incomprehensible?		10	8	80	*Audio quality good. Occasional rasping or static.*
Timeliness of Audio - Does the audio arrive within two seconds? Faster is highly desirable		8	3	24	Quality of audio should be understandable at 1 sec delay, near perfect at 2 sec delay. *Bad delays, up to 5 seconds.*
Quality of Video - Resolution For general use needed to establish context, 160x120 (pixels) is a minimum. For detailed shots, 320x240 is a minimum, while 640x480 is preferred and may be necessary depending upon the task.		10	7	70	*320x240 resolution possible.*
Quality of Video - Frame Rate For general use needed to establish context, 5 frames per second is a minimum. For detailed shots, slower frame rates are acceptable, but this is task dependent.		9	3	27	*1 frame per second*

Table A-1-2 WhitePine CUSeeMe 3.0 (Continued)

Quality of Video - Color Depth For black and white cameras, 64 shades of gray need to be supported. For color cameras, 256 colors need to be supported.	**6**	**10**	**60**	*64 shades of gray supported*
Timeliness of Video Video frames should be delayed less than two seconds.	**5**	**8**	**40**	Previous video frames help to mitigate video frame delays. Delay of about 1.5 seconds.
Ease of Use Minimize cognitive load Minimize possibility of error	**10**	**7**	**70**	*Relatively simple, directory appears on start up.*
Learnability The system should essentially be "walk up and use" for the end-users. A maximum of 5 minutes training to operate the system effectively.	**10**	**8**	**80**	*Simplicity leads to faster initial successful use.*
2.0 Reliability				
Not Applicable				
3.0 Maintainability				
Not Applicable				
4.0 Producibility				
Not Applicable				
5.0 Capability				
Shared Application View	**5**	**0**	**0**	Can users view a common app?
Shared Application Control	**5**	**0**	**0**	Can users control a common app?

Table A-1-2 WhitePine CUSeeMe 3.0 (Continued)					
Multiple Shared Application Participants		4	0	0	Can more than two users share an app?
Sharing Technology Multicast (excellent), reflector (good), star topology (okay)		4	10	40	Which technology is used to allow multiple shared application and/or whiteboard and/or audio/video participants? *Multicast technology.*
Integratable Whiteboard Tool		6	0	0	Can the whiteboard tool be directly integrated into other applications?
Image Capture to Whiteboard		6	3	18	Can video images be captured directly to the whiteboard?
Multiple Whiteboard Participants		4	9	36	Can more than two users access whiteboard simultaneously?
Whiteboard Standards Adherence to International Telecommunication Union (ITU) T.120		5	10	50	Will the whiteboard tool interoperate with other products?
Bandwidth Adaptable Can the collaboration software be optimized for bandwidth available on a wireless LAN communication (1-2mb/sec)		7	9	63	Can the collaboration software adapt to available bandwidth?
Ability to Alter Audio Quality		6	4	24	This criterion and the next three deal with the ability to trade-off bandwidth resources
Ability to Alter Audio Timeliness		6	2	12	
Ability to Alter Video Quality		6	9	54	
Ability to Alter Video Timeliness		6	4	24	
Audio/Video Synchronization The closer the audio and video are kept synchronized, the better. A goal of 0.5 seconds is desirable.		8	3	24	Is the audio and video kept in synchronization? *2-3 second delay between audio and video.*

Table A-1-2 WhitePine CUSeeMe 3.0 (Continued)					
Multiple Audio/Video Participants		8	10	80	Can more than two users videoconference simultaneously?
Audio/Video Standards - Adherence to ITU H.323		5	10	50	Will the videoconferencing tool interoperate with other products?
Image Capture Can a bitmap (.BMP), GIF, or JPEG image be captured?		6	3	18	Can an image (video still) be captured and output?
Dynamically Enable/Disable Audio/Video		9	10	90	Can the videoconferencing tool release the audio/video drivers so that other audio/video tools can access those resources?
Dynamically Control Audio/Video Quality and Timeliness Tradeoffs		8	9	72	Can quality and timeliness tradeoffs be made on-the-fly?
Can the Video Picture be Zoomed? (zoom in/zoom out)		8	5	40	
Change Microphone Capture Mode		8	7	56	Can the microphone be set to 'open', 'push to talk', or 'voice activated'? *All*
Initiate and Control Collaboration Session		9	4	36	Can a collaboration session be fully started without keyboard input (e.g., via scripts)?
API to Capture Images		6	0	0	
API to Manipulate Video Window		6	0	0	
Independent Video Window		6	10	60	Is the video window independent of other collaboration windows?
Add/Remove Audio/Video Codecs		4	10	40	Can additional compression components be added at a later date?
Filter Out Ambient Audio Noise (echo cancellation)		4	7	28	Can the software filter out noise?
Cost per Seat less than $100		8	3	24	*About $70*
		Total:	176	1390	

Table A-1-3 VocalTec InternetPhone 5.0					
Criteria	**Rqmts**	**Weight**	**Score**	**Total**	**Comments**
1.0 Performance					Quality and timeliness criteria are highly related and can't be judged independently of one another. A gain in one area will cause degradation in another. An ideal tool will find the best balance amongst the criteria for the available network bandwidth.
Quality of Audio - Is the audio understandable? Does the audio breakup, or is the audio distorted, to the point of being incomprehensible?		10	3	30	*Audio was badly mangled. Some phrases came through ok, but most were somewhat or completely unintelligible.*
Timeliness of Audio - Does the audio arrive within two seconds? Faster is highly desirable		8	3	24	Quality of audio should be understandable at 1 sec delay, near perfect at 2 sec delay. *About 3 second delay.*
Quality of Video - Resolution For general use needed to establish context, 160x120 (pixels) is a minimum. For detailed shots, 320x240 is a minimum, while 640x480 is preferred and may be necessary depending upon the task.		10	6	60	*320x200 available*
Quality of Video - Frame Rate For general use needed to establish context, 5 frames per second is a minimum. For detailed shots, slower frame rates are acceptable, but this is task dependent.		9	3	27	*Worse than 1 frame per 5 seconds*

Table A-1-3 VocalTec InternetPhone 5.0 (Continued)

Quality of Video - Color Depth For black and white cameras, 64 shades of gray need to be supported. For color cameras, 256 colors need to be supported.		6	10	60	*64 shades of gray supported*
Timeliness of Video Video frames should be delayed less than two seconds.		5	3	15	Previous video frames help to mitigate video frame delays.
Ease of Use Minimize cognitive load Minimize possibility of error		10	4	40	*Poor performance on basic functionality*
Learnability The system should essentially be "walk up and use" for the end-users. A maximum of 5 minutes training to operate the system effectively.		10	7	70	
2.0 Reliability					
Not Applicable					
3.0 Maintainability					
Not Applicable					
4.0 Producibility					
Not Applicable					
5.0 Capability					
Shared Application View		5	0	0	Can users view a common app?
Shared Application Control		5	0	0	Can users control a common app?
Multiple Shared Application Participants		4	0	0	Can more than two users share an app?

Table A-1-3 VocalTec InternetPhone 5.0 (Continued)					
Sharing Technology Multicast (excellent), reflector (good), star topology (okay)		4	4	16	Which technology is used to allow multiple shared application and/or whiteboard and/or audio/video participants? *Star topology used.*
Integratable Whiteboard Tool		6	0	0	Can the whiteboard tool be directly integrated into other applications?
Image Capture to Whiteboard		6	6	36	Can video images be captured directly to the whiteboard?
Multiple Whiteboard Participants		4	10	40	Can more than two users access whiteboard simultaneously?
Whiteboard Standards Adherence to International Telecommunication Union (ITU) T.120		5	10	50	Will the whiteboard tool interoperate with other products?
Bandwidth Adaptable Can the collaboration software be optimized for bandwidth available on a wireless LAN communication (1-2mb/sec)		7	6	42	Can the collaboration software adapt to available bandwidth?
Ability to Alter Audio Quality		6	2	12	This criterion and the next three deal with the ability to trade-off bandwidth resources
Ability to Alter Audio Timeliness		6	4	24	
Ability to Alter Video Quality		6	3	18	
Ability to Alter Video Timeliness		6	3	18	
Audio/Video Synchronization The closer the audio and video are kept synchronized, the better. A goal of 0.5 seconds is desirable.		8	0	0	Is the audio and video kept in synchronization? *A disparity of as much as 5 seconds was noticed.*

Table A-1-3 VocalTec InternetPhone 5.0 (Continued)					
Multiple Audio/Video Participants		8	10	80	Can more than two users videoconference simultaneously?
Audio/Video Standards - Adherence to ITU H.323		5	10	50	Will the videoconferencing tool interoperate with other products?
Image Capture Can a bitmap (.BMP), GIF, or JPEG image be captured?		6	6	36	Can an image (video still) be captured and output?
Dynamically Enable/Disable Audio/Video		9	0	0	Can the videoconferencing tool release the audio/video drivers so that other audio/video tools can access those resources?
Dynamically Control Audio/Video Quality and Timeliness Tradeoffs		8	0	0	Can quality and timeliness tradeoffs be made on-the-fly?
Can the Video Picture be Zoomed? (zoom in/zoom out)		8	7	56	
Change Microphone Capture Mode		8	6	48	Can the microphone be set to 'open', 'push to talk', or 'voice activated'?
Initiate and Control Collaboration Session		9	0	0	Can a collaboration session be fully started without keyboard input (e.g., via scripts)?
API to Capture Images		6	0	0	
API to Manipulate Video Window		6	0	0	
Independent Video Window		6	10	60	Is the video window independent of other collaboration windows?
Add/Remove Audio/Video Codecs		4	8	36	Can additional compression components be added at a later date?
Filter Out Ambient Audio Noise (echo cancellation)		4	6	24	Can the software filter out noise?
Cost per Seat less than $100		8	5	40	*About $50*
		Total:	155	1012	

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Table A-1-4 Intel Internet Video Phone 2.0					
Criteria	Rqmt s	Weigh t	Score	Tota l	Comments
1.0 Performance					Quality and timeliness criteria are highly related and can't be judged independently of one another. A gain in one area will cause degradation in another. An ideal tool will find the best balance amongst the criteria for the available network bandwidth.
Quality of Audio - Is the audio understandable? Does the audio breakup, or is the audio distorted, to the point of being incomprehensible?		10	2	20	*Audio badly mangled. Hard to get a single word though clearly. Many phrases completely disappear.*
Timeliness of Audio - Does the audio arrive within two seconds?☐Faster is highly desirable		8	7	56	Quality of audio should be understandable at 1 sec delay, near perfect at 2 sec delay. *About 3 seconds delay.*
Quality of Video - Resolution For general use needed to establish context, 160x120 (pixels) is a minimum. For detailed shots, 320x240 is a minimum, while 640x480 is preferred and may be necessary depending upon the task.		10	0	0	*Video would not transmit.*
Quality of Video - Frame Rate For general use needed to establish context, 5 frames per second is a minimum. For detailed shots, slower frame rates are acceptable, but this is task dependent.		9	0	0	*Video would not transmit.*

Table A-1-4 Intel Internet Video Phone 2.0 (Continued)

Quality of Video - Color Depth For black and white cameras, 64 shades of gray need to be supported. For color cameras, 256 colors need to be supported.		6	0	0	*Video would not transmit.*
Timeliness of Video Video frames should be delayed less than two seconds.		5	0	0	Previous video frames help to mitigate video frame delays.
Ease of Use Minimize cognitive load Minimize possibility of error		10	3	30	*Poor performance in basic functionality*
Learnability The system should essentially be "walk up and use" for the end-users. A maximum of 5 minutes training to operate the system effectively.		10	6	60	
2.0 Reliability					
Not Applicable					
3.0 Maintainability					
Not Applicable					
4.0 Producibility					
Not Applicable					
5.0 Capability					
Shared Application View		5	0	0	Can users view a common app?
Shared Application Control		5	0	0	Can users control a common app?
Multiple Shared Application Participants		4	0	0	Can more than two users share an app?

Table A-1-4 Intel Internet Video Phone 2.0 (Continued)				
Sharing Technology Multicast (excellent), reflector (good), star topology (okay)	4	7	28	Which technology is used to allow multiple shared application and/or whiteboard and/or audio/video participants? *Reflector technology used.*
Integratable Whiteboard Tool	6	0	0	Can the whiteboard tool be directly integrated into other applications?
Image Capture to Whiteboard	6	0	0	Can video images be captured directly to the whiteboard?
Multiple Whiteboard Participants	4	0	0	Can more than two users access whiteboard simultaneously?
Whiteboard Standards Adherence to International Telecommunication Union (ITU) T.120	5	0	0	Will the whiteboard tool interoperate with other products?
Bandwidth Adaptable Can the collaboration software be optimized for bandwidth available on a wireless LAN communication (1-2mb/sec)	7	8	56	Can the collaboration software adapt to available bandwidth?
Ability to Alter Audio Quality	6	0	0	This criterion and the next three deal with the ability to trade-off bandwidth resources
Ability to Alter Audio Timeliness	6	0	0	
Ability to Alter Video Quality	6	0	0	
Ability to Alter Video Timeliness	6	0	0	
Audio/Video Synchronization The closer the audio and video are kept synchronized, the better. A goal of 0.5 seconds is desirable.	8	0	0	Is the audio and video kept in synchronization? *No video images available for comparison.*

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Table A-1-4 Intel Internet Video Phone 2.0 (Continued)					
Multiple Audio/Video Participants		8	0	0	Can more than two users videoconference simultaneously?
Audio/Video Standards - Adherence to ITU H.323		5	10	50	Will the videoconferencing tool interoperate with other products?
Image Capture Can a bitmap (.BMP), GIF, or JPEG image be captured?		6	0	0	Can an image (video still) be captured and output?
Dynamically Enable/Disable Audio/Video		9	0	0	Can the videoconferencing tool release the audio/video drivers so that other audio/video tools can access those resources?
Dynamically Control Audio/Video Quality and Timeliness Tradeoffs		8	2	16	Can quality and timeliness tradeoffs be made on-the-fly?
Can the Video Picture be Zoomed? (zoom in/zoom out)		8	0	0	
Change Microphone Capture Mode		8	10	80	Can the microphone be set to 'open', 'push to talk', or 'voice activated'?
Initiate and Control Collaboration Session		9	0	0	Can a collaboration session be fully started without keyboard input (e.g., via scripts)?
API to Capture Images		6	0	0	
API to Manipulate Video Window		6	0	0	
Independent Video Window		6	0	0	Is the video window independent of other collaboration windows?
Add/Remove Audio/Video Codecs		4	0	0	Can additional compression components be added at a later date?
Filter Out Ambient Audio Noise (echo cancellation)		4	5	20	Can the software filter out noise?
Cost per Seat less than $100		8	10	80	*Free*
		Total:	60	496	

4.0 Product Experience

As an all-in-one solution, NetMeeting cannot be beaten. It is the only software system the authors are aware of that offers the full suite of collaborative technologies. Other products may excel at individual technologies. Often times, this excellence comes at the expense of dedicated hardware or non-standards-based algorithms. For example, CUSeeMe version 2.1.1 did not support the ITU H.323 audio/video standard. The authors have yet to find a product with the quality of that version's audio and video. Standards compliance often comes with performance penalties.

5.0 Source Summary

Company	Product Name / Contact
Intel	Internet Video Phone 2.0 with Proshare Technology http://connectedpc.com/iaweb/cpc/iivphone/index.htm
Microsoft	NetMeeting 2.0 http://www.microsoft.com/netmeeting/
VocalTec	InternetPhone 5.0 with Video http://www.vocaltec.com/products/iphone5/index.html
WhitePine	CUSeeMe 3.0 http://www.cuseeme.com/cu30-win.html
DataBeam	FarSite http://www.databeam.com/Products/FarSite/
PictureTel	LiveShare Plus http://www.picturetel.com/liveshrp.htm

A-2. Database Management Systems Trade Study

1.0 Summation

1.1 Purpose

The purpose of the Database Management Systems (DBMSs) trade study is to investigate and evaluate the current state of the art of DBMSs and recommend the best candidate that fulfills the requirements for the ITI-ALC Program Phase II. The primary requirement for the DBMS is to support the Computerized Maintenance Management System (CMMS) chosen by the ITI-ALC team. Secondarily the DBMS will be utilized to support most ITI-ALC Program Phase II functionality that requires persistent data storage, such as but not limited to the following:

- Mechanics real-time annotation (both written and spoken)
- Three-dimensional models such as VRML
- Diagnostic information
- Streaming audio and video
- Electronic technical manuals
- Digitized still images
- Illustrations, graphics, and schematics

1.2 Products

For the purpose of this trade study a Database Management System will be defined as and have the following characteristics:

- A set of software packages (tools) and servers (processes) that manage persistent data stores
- Support for simple datatypes such as integers, scientific floating-point, character strings, date/time, and money
- Extendable to handle "rich" datatypes or "objects" that represent complex internal structures, attributes, and behavior and that support new search methods
- Intrinsically "aware" of new datatypes
- Support for queries of both simple and complex datatypes
- Supported by leading CMMS products

The methodology employed to downselect the DBMS products started by considering the available DBMS technologies. Candidate DBMS technologies were analyzed to determine which DBMS technology best meets the program's needs. The initial DBMSs technology candidates considered included Relational Database Management System (RDBMS), Object-Oriented Database Management System (OODBMS), and Object/Relational Database Management System (O/RDBMS). The candidate DBMS technology that best represented the definition of this trade study was O/RDBMS technology.

Candidate O/RDBMS products were gathered, analyzed, and downselected based on CMMS support, technical quality, maturity, and market share. IBM Universal Database was initially considered for evaluation but was not downselected because none of the CMMSs under consideration worked with the product. The following products where evaluated for the DBMSs trade study:

Company	Product	Version
Informix Inc.	INFORMIX-Universal Server	v9.11 Beta
Oracle Corp.	ORACLE8 Universal Server	v8.0.3
Sybase Inc.	Adaptive Server	v11.5 Beta

1.3 Environment

The computer used to evaluate the three DBMS products was a Dell Windows NT 4.0 workstation, containing an Intel Pentium-133 MHz processor, 96 MB of RAM, and 8.4 GB of disk.

1.4 Summary of Best Candidate

Out of the three leading DBMS technologies reviewed, O/RDBMS technology was deemed to best fit the ITI-ALC program's requirements, for both demonstration and production. O/RDBMS technology was selected due to O/RDBMSs strong querying capabilities of complex datatypes.

O/RDBMSs are able to intelligently manage complex data not as binary large objects (BLOBs) but natively as objects. This means very high performance query and transaction access to rich complex data. O/RDBMSs provide an SQL interface for rapid application development and maintenance, as well as delivering scalability and manageability. O/RDBMSs allow you to define both the structure and behavior of data needed to define particular applications. O/RDBMS servers can make intelligent choices to optimize access to the complex data, and users can define functions that manipulate the data right in the server itself, or take advantage of datatype and function extensions written by others.

The three-downselected O/RDBMS products all employ different approaches to implementing an O/RDBMS:

- Sybase's approach employs a separate servers single operational model. In Sybase separate servers single operational model approach relational and specialty datatypes are stored in separate data stores. Separate servers are held together by a glue layer, which is managed and monitored by common services.
- Oracle's approach employs middleware simulation (object simulator). The object simulator simulates specialized object-relational functionality outside the DBMS in a middleware layer. This approach involves little RDBMS changes; rather, it puts a specialized wrapper or simulator around the DBMS.
- Informix employs a hybrid (object top) approach. In the object top approach Informix rewrote the "top half" of its relational engine to support object-relational functionality, including extensible, complex datatypes. This approach involved building the upper half of an object-relational engine and then layering it onto the storage manager and transaction system of a their RDBMS.

Sybase's Adaptive Server was not selected due to low trade study assessment score and deficiencies in defining complex datatypes, as reflected in the Trade Study Assessment Table. Sybase's Adaptive Server extendable O/RDBMS approach is less desirable when compared to the other two approaches. Sybase's Adaptive Server is less desirable because of the inability for the user to easily extend the DBMS if at all. Also since Sybase's Adaptive Server architecture has loosely coupled servers a relational engine and specialty data engines all held together by a glue layer data is stored in different servers depending on their datatype. Therefore, this object-simulation environment will require cross-server joins for queries that select data from multiple servers, which should cause costly performance

hits due to server coordination coordinated by the glue layer.

However, Sybase's Adaptive Server comes with a comprehensive set of tools that seemed to be both solid and dependable. Sybase's technical support system seems to be a little less then adequate with an average four hours turn around time after call is placed. Sybase's Adaptive Server price per concurrent seat is good but the maintenance structure is less then desirable. For these, reason Sybase's Adaptive Server is deemed inadequate for both the ITI-ALC program demonstration and production.

Informix's INFORMIX-Universal Server had the second highest Trade Study Assessment Score, which only trailed Oracle's ORACLE8 Universal Server score by sixteen raw points and one hundred and fifteen weighted points. Informix's INFORMIX-Universal Server extendable O/RDBMS approach is the most desirable when compared to the other two approaches. The reasoning behind the preference for the INFORMIX-Universal Server extendable O/RDBMS approach is listed below:
- Informix tightly integrates new datatypes with the DBMS server through its DataBlade API; Oracle loosely couples with new datatypes through CORBA.
- The notion that the DBMS server is intrinsically aware of new datatypes in a fashion similar to native RDBMS datatypes such as integer.
- The extendibility of the indexing and optimization system due to the DBMS server awareness of new datatypes.
- The theoretical performance difference between extending O/RDBMS server through a fast server based local API versus a network based API.

Informix's INFORMIX-Universal Server appears to be a technically competent package. However, Informix failed to provide the INFORMIX-Universal Server in time for a lengthy evaluation and to provide adequate technical support for the evaluation. In their defense, Informix did warn about difficulties of getting technical support so late in the Beta cycle. Informix's INFORMIX-Universal Server for the Windows NT platform is expected to be generally available in December 1997. Informix's INFORMIX-Universal Server lacked server side CORBA support and Lockheed Martin Information Systems has very little to no experience with Informix products. Informix INFORMIX-Universal Server comes with a comprehensive set of tools but the trade study assessor had difficulties in setup with some of the tools and some were just not available for evaluation.

In addition, a stable company does not back Informix's INFORMIX-Universal Server currently even though Informix enjoys the second largest market share in the DBMS industry. Informix's INFORMIX-Universal Server price per concurrent seat and maintenance structure is higher than Oracle's without additional price negotiations. For these reasons Informix's INFORMIX-Universal Server is not deemed preferable at this time.

Of the three O/RDBMS products evaluated, Oracle ORACLE8 Universal Server was deemed most preferable. Oracle ORACLE8 Universal Server had the highest Trade Study Assessment Score, has a CORBA based open architecture, and Lockheed Martin Information Systems company has over seven years of experience with Oracle products. While the Oracle ORACLE8 Universal Server extendable O/RDBMS approach is less desirable than Informix O/RDBMS's approach, it is still capable of supporting ITI-ALC program needs. A stable company backs ORACLE8 Universal Server and Oracle enjoys the largest market share in the DBMS industry. In addition, Oracle ORACLE8 Universal Server comes with a comprehensive set of tools that are both solid and dependable. Oracle has also built a

strong technical support system. Oracle ORACLE8 Universal Server price per concurrent seat and maintenance structure is also appealing. For these, reason Oracle ORACLE8 Universal Server is deemed preferable for both the ITI-ALC program demonstration and production.

1.5 Evaluation of Other Products/Tools

The two DBMS candidate technologies not selected each have their own strengths that make them appropriate for particular classes of data management problems. However, neither one completely meets the DBMS criteria set forth by this trade study.

RDBMSs provide high-speed, short-running queries and transactions on simple data. A modern RDBMS is scalable, robust, and manageable, and provides access to data by content, using the SQL language for phrasing queries. It is an excellent platform for developing applications for both high-speed transactions and flexible decision support on its supported datatypes.

However, existing RDBMSs provide only limited support for complex data, which they store as BLOBs that cannot be indexed, searched, or manipulated within the server.

OODBMSs provide persistent storage for complex objects manipulated by object-oriented (OO) programming languages like C++ and SmallTalk. Applications written in these languages expect to follow pointers to locate data and rely on the OODBMS to support a large virtual memory space. Because the fundamental way to navigate through an OODBMS is by pointer following, provision of a highly optimized query language has not been a major concern for OODBMS vendors. The OODBMSs currently available do not scale well either over very large data stores or very large numbers of users, a problem handled well by some of the RDBMS products.

Typical applications of an OODBMS are for a small number of users to perform complex manipulations of object collections in the tens of megabytes range. Examples include the manipulation of CAD (computer-aided design) drawings and other complex, structured data.

The two DBMS technologies discussed above fail to provide either complex data support or highly scalable and robust query access to large data stores.

1.6 Future Considerations

The Database Management System market place is very dynamic. It is worthwhile to keep track of the state of the products available, since the currently leading products and the condition and responsiveness of their producing companies have the potential for swift change.

2.0 Trade Study Information

2.1 Informix INFORMIX-Universal Server Architecture Summary

INFORMIX-Universal Server (IUS) (Table A-2-1), O/RDBMS architecture is based on two technologies: Informix Dynamic Scalable Architecture (DSA) and Illustra DataBlade technology. Dynamic Scalable Architecture provides scalability with parallel processing at the core of its architecture. INFORMIX-Universal Server can be extended to manage new kinds of data by means of DataBlade modules. DataBlade modules define new data structures, new functions that manipulate them, and optionally new access methods to provide fast access to the data. A DataBlade module enables the database server to provide the same level of support for new data types that it provides for built-in data types. DataBlade modules can be thought of as an object-oriented package, similar to a C++ class that encapsulates specialized data types, such as images.

The important architectural components of Dynamic Scalable Architecture and DataBlade technology are:

- Dynamic Scalable Architecture - provides high scalability with parallel processing and the ability to dynamically adjust database parameters
- "Pluggable" objects called DataBlade modules that are manageable and provide extensible functionality, including geo-spatial data, time series data, multi-media, and image content and text.
- DataBlade API - standardizes interfaces that enable server extension
- Integrated development and management of DataBlade modules.

2.2 Oracle ORACLE8 Universal Server Architecture Summary

ORACLE8 Universal Server (Table A-2-2), O/RDBMS architecture is based on Oracle's Network Computing Architecture (NCA). Network Computing Architecture is based on open technologies and standards. At the core of Network Computing Architecture are the open and de facto standards: HTTP/HTML, CORBA 2.0 and Java.

The Network Computing Architecture combines the Web technologies of HTTP and HTML with the object technologies of CORBA 2.0 to form the basis for a distributed computing environment. CORBA provides Network Computing Architecture with a distributed-object environment, which includes IIOP for object interoperability and IDL for language-neutral interfaces. The Network Computing Architecture uses Java to provide extensibility, portability, and a de facto programming language throughout the architecture but Java is not available (server side) in the first release. The Network Computing Architecture also supports ActiveX/COM clients through open COM/CORBA interoperability specifications.

The important architectural components of Network Computing Architecture are:
- "Pluggable" objects called cartridges that are manageable and provide extensible functionality, which includes support for geo-spatial data, time series data, multi-media, and image content and text.
- Open protocols and standardized interfaces that enable communication among cartridges through a software bus called Inter-Cartridge Exchange (ICX).
- Extensible clients, application servers, and database servers.
- A family of clients:
  - Oracle's Web Application Server
  - Oracle's universal data server
- Integrated development and management of cartridges.

2.3 Sybase Adaptive Server Architecture Summary

Adaptive Server (Table A-2-3), O/RDBMS architecture is one part of the Adaptive Component Architecture. The Adaptive Component Architecture provides a single operational model (management services) for middle-tier servers as well as data servers. The Adaptive Server Architecture brings the existing Sybase database products into a unified architecture with:
- Optimized data stores and access methods
- Single programming model across each of data stores
- Single operational model across stores
- Specialty datatypes in their own data stores
- Transaction-based processing across each of these data stores

The Sybase Adaptive Server strategy is based on the hypothesis that some features of a data server need to be optimized for specific purposes, while other features need to be common across all configurations. Adaptive Server provides separate components for each of the server tasks. In this way, Sybase states optimized components for data access can coexist with a Common Language Component and other components for accessing specialty data types.

The important architectural components of Adaptive Component Architecture are:
- Common Language Processor - provides a consistent language, interface across all data stores.
- Component Integration Layer - provides access to specialty datatypes, relational data stored in other vendors' databases, and distributed data access.
- Optimized relational data stores - Data access and storage are linked. Indexing systems, management requirements, and other aspects of data storage are features of the data store (the data access engine and associated physical store).
- Specialty datatype stores - Specialty datatypes, including geo-spatial data, time series data, multi-media, image content and text, reside in their own data stores.
- Single operational model - Management and monitoring services will be shared across all stores, to enable system-wide administration.

3.0 Trade Study Assessment Tables

3.1 Informix Trade Study Assessment Tables

Table A-2-1 Informix INFORMIX-Universal Server for Window NT v9.11 Beta					
CRITERIA	**RQMTS**	**WEIGHT**	**SCORE**	**TOTAL**	**COMMENTS**
1.0 Performance					
1.1 Cost-based, syntax-independent optimization		6	8	48	Statistics are kept current by manually issuing analyzing schema command(s). Query plan will be affected if statistics are too far out of date. Table-driven extensible query optimizer
1.2 Shared database buffer, data dictionary, SQL statements, and stored procedures cache		6	6	36	
1.3 B-tree single and concatenated column indexes		6	8	48	Extensible indexing system through DataBlades

Table A-2-1 Informix INFORMIX-Universal Server for Window NT v9.11 Beta (Continued)					
1.4	Contention-free, non-blocking, multi-version, and read-consistent queries		10	6	60	By default, each insert, update, and delete statement is considered a single transaction. For contention-free, non-blocking, multi-version, and read-consistent queries you have to explicitly define transactions
1.5	Unique sequence number generation		5	3	15	Only Serial/Serial8 column datatype - only one per table allowed
1.6	Unrestricted row-level locking without lock escalation		10	6	60	
			43	**37**	**267**	

2.0 Reliability

Not Applicable					

3.0 Maintainability

3.1	Cost Of Ownership		5	5	25	License - Minimum 10 seats - Cost $12600 Technical Support/Upgrades - Business hours - Unlimited calls - Technical support cost $2695 - Update subscription free with support
3.2	Graphical installer and ease of installation		5	6	30	

Table A-2-1 Informix INFORMIX-Universal Server for Window NT v9.11 Beta (Continued)					
3.3 Documentation		7	6	42	IPDF based - Not capable of searching multiple documents - Good technical information - Some links provided
3.4 Systems Manager- GUI and easy to use		6	6	36	
		23	**23**	**133**	
4.0 Producibility					
Not Applicable					
5.0 Capability					
5.1 Database Triggers					
5.1.1 Triggers execute on INSERT, UPDATE, or DELETE either BEFORE or AFTER operations		7	8	56	Can also place triggers on select statements
5.1.2 Triggers fire once per statement or once per row		7	6	42	
		14	**14**	**98**	
5.2 Declarative Integrity Constraints					
5.2.1 Cascade updates and deletes		7	3	21	Delete only
5.2.2 Constraint checking at end of statements		7	6	42	

Table A-2-1 Informix INFORMIX-Universal Server for Window NT v9.11 Beta (Continued)

5.2.3 PRIMARY, FOREIGN, and UNIQUE keys, CHECK, DEFAULT, and not NULL constraints		10	6	60	
		24	**15**	**123**	
5.3 Miscellaneous					
5.3.1 CMMS Dependencies		10	3	30	Revere product only
5.3.2 CORBA IIOP support		6	0	0	None
5.3.3 LMIS product experience		10	0	0	None
5.3.4 View support		5	6	30	
5.3.5 Extendable Object-Relational Database Architecture		10	10	100	IUS is extendable by adding DataBlade modules. The database server is intrinsically aware of new datatypes added to the system. It has a Table-driven extensible query optimizer and an extensible indexing system.
		41	**19**	**160**	

Table A-2-1 Informix INFORMIX-Universal Server for Window NT v9.11 Beta (Continued)					
5.4 Object Types Support					
5.4.1 User-defined types (UDTs) support for hierarchies of types, inheritance, and Object ID reference pointers		10	8	80	Distinct types, opaque abstract datatypes (ADTs), row types, and collection types, including unlimited nested tables. IUS supports single inheritance among a hierarchy of named row types. In addition, any table that is based on a row type becomes a typed table that can also be part of a hierarchy. Reference types and SQL3 ADTS are coming, as is replication of UDT data.
5.4.2 Internal and external support for large objects (LOBs)		10	8	80	LOBs can be stored inside the database (in smart BLOBs) or in external files. IUS does not guarantee the integrity of data stored in external files, but Informix has future plans in this area. A virtual table interface allows external data to be registered in the database catalogs and accessed as if they were IUS tables.

Table A-2-1 Informix INFORMIX-Universal Server for Window NT v9.11 Beta (Continued)				
5.4.3 User-defined functions (UDFs) with function overloading		10	6	60	A full range of UDF types plus support for overloading, function resolution based on multiple attributes, and parallel execution of functions where appropriate.
		30	**22**	**220**	

5.5 Programmatic Interfaces

5.5.1 ODBC and JDBC		10	6	60	
5.5.2 Support for 3GLs, 4GLs, and Object-oriented languages		10	6	60	
		20	**12**	**120**	

5.6 Security, Roles and Privileges

5.6.1 Encrypted passwords with choice of internal or external user authentication		5	3	15	Uses system account to establish database account (external user authentication only)
5.6.2 Fine-grained database privileges		6	5	30	
5.6.3 Hierarchical role-based security for group-level access control		6	6	36	
		17	**14**	**81**	

5.7 Stored Procedures

Table A-2-1 Informix INFORMIX-Universal Server for Window NT v9.11 Beta (Continued)					
5.7.1 Block structure flow control with robust exception handling, remote procedure calls (RPCs) protected by a transparent two-phase commit, and static and dynamic SQL support		10	6	60	
5.7.2 Called from 3GL and other stored procedures, database triggers and SQL statements		10	6	60	
5.7.3 Cursor variables for easy retrieval of multi-row result sets		5	6	30	
		25	18	150	
TOTALS		237	174	1352	

3.2 Oracle Trade Study Assessment Tables

CRITERIA	RQMTS	WEIGHT	SCORE	TOT	COMMENTS
Table A-2-2 Oracle ORACLE8 Windows NT Enterprise v8.03					
1.0 Performance					
1.1 Cost-based, syntax-independent optimization		6	6	36	Statistics are kept current by manually issuing analyzing schema command(s). Query plan will be affected if statistics are too far out of date.
1.2 Shared database buffer, data dictionary, SQL statements, and stored procedures cache		6	6	36	
1.3 B-tree single and concatenated indexes		6	6	36	
1.4 Contention-free, non-blocking, multi-version, and read-consistent queries		10	7	70	Transactions are implicit
1.5 Unique sequence number generation		5	6	30	
1.6 Unrestricted row-level locking without lock escalation		10	6	60	
		43	**37**	**268**	

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Table A-2-2 Oracle ORACLE8 Windows NT Enterprise v8.03 (Continued)					
2.0 Reliability					
Not Applicable					
3.0 Maintainability					
3.1 Cost Of Ownership		5	6	30	License - Minimum 8 seats - Cost $7960 Technical Support/Upgrades - Normal business hours - Unlimited calls - Technical support cost $1600 - Update subscription free with support
3.2 Graphical installer and ease of installation		5	6	30	
3.3 Documentation		7	5	35	HTML based - Not capable of searching multiple documents - Good technical information - Some broken links
3.4 Systems Manager-GUI and easy to use		6	6	36	
		23	**23**	**131**	
4.0 Producibility					
Not Applicable					

Table A-2-2 Oracle ORACLE8 Windows NT Enterprise v8.03 (Continued)				
5.0 Capability				
5.1 Database Triggers				
5.1.1 Triggers execute on INSERT, UPDATE, or DELETE either BEFORE or AFTER operations		7	6	42	
5.1.2 Triggers fire once per statement or once per row		7	6	42	
		14	**12**	**84**	
5.2 Declarative Integrity Constraints				
5.2.1 Cascade updates and deletes		7	3	21	Delete only
5.2.2 Constraint checking at end of statements		7	7	49	Also can check constraint at end of transactions
5.2.3 PRIMARY, FOREIGN, and UNIQUE keys, CHECK, DEFAULT, and not NULL constraints		10	6	60	
		24	**16**	**130**	
5.3 Miscellaneous				
5.3.1 CMMS Dependencies		10	10	100	Revere, TSW, and GOLD products
5.3.2 CORBA IIOP support		6	6	36	
5.3.3 LMIS product experience		10	10	100	
5.3.4 View support		5	6	30	

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Table A-2-2 Oracle ORACLE8 Windows NT Enterprise v8.03 (Continued)					
5.3.5 Extendable Object-Relational Database Architecture		10	5	50	Data Cartridge
		41	37	316	
5.4 Object Types Support					
5.4.1 User-defined types (UDTs) support for hierarchies of types, inheritance, and Object ID reference pointers		10	4	40	Oracle8's extended type system supports object, collection (varying arrays and nested tables), and reference types. An object type can apply to either a column or a row and can be semantically equivalent to a SQL3-named row type. Oracle8 also explicitly associates methods with object types. Only one level of nested tables is supported in 8.0, which limits object-modeling capability. Oracle8 does not yet support the notion of a fully encapsulated abstract datatypes. Oracle8 will support single inheritance with Database Extensibility Services. Extended types cannot be replicated. No inheritance; single inheritance coming in 8.1

Table A-2-2 Oracle ORACLE8 Windows NT Enterprise v8.03 (Continued)					
5.4.2 Internal and external support for large objects (LOBs)		10	4	40	Large objects can be stored inside the database or in external files. Oracle8 does not support write access to or guarantee the integrity of external data. LOBs can be replicated, but tables with LOBs cannot be partitioned.
5.4.3 User-defined functions (UDFs) with function overloading		10	6	60	Scalar UDFs, overloading, function resolution based on multiple attributes, and parallel execution of UDFs with user-defined aggregates (column functions) is under consideration.
		30	**14**	**140**	

5.5 Programmatic Interfaces

5.5.1 ODBC and JDBC		10	6	60	
5.5.2 Support for 3GLs, 4GLs, and Object-oriented languages		10	6	60	
		20	**12**	**120**	

5.6 Security, Roles and Privileges

5.6.1 Encrypted passwords with choice of internal or external user authentication		5	6	30	
5.6.2 Fine-grained database privileges		6	7	42	

Table A-2-2 Oracle ORACLE8 Windows NT Enterprise v8.03 (Continued)				
5.6.3 Hierarchical role-based security for group-level access control	6	6 .	36	
	17	19	108	
5.7 Stored Procedures				
5.7.1 Block structure flow control with robust exception handling, remote procedure calls (RPCs) protected by a transparent two-phase commit, and static and dynamic SQL support	10	8	80	Ada like syntax and structure
5.7.2 Called from 3GL and other stored procedures, database triggers and SQL statements	10	6	60	
5.7.3 Cursor variables for easy retrieval of multi-row result sets	5	6	30	
	25	20	170	
TOTALS	237	190	1467	

3.3 Sybase Trade Study Assessment Tables

Table A-2-3 Sybase Adaptive Server Enterprise Windows NT v11.5 Beta					
CRITERIA	**RQMTS**	**WEIGH**	**SCORE**	**TOTAL**	**COMMENTS**
1.0 Performance					
1.1 Cost-based, syntax-independent optimization		6	7	42	The server for each query analyzes affected tables automatically. So query plan should not be affected by out of date statistics but additional overhead created by gathering for each query could possibility slow the query.
1.2 Shared database buffer, data dictionary, SQL statements, and stored procedures cache		6	6	36	
1.3 B-tree single and concatenated column indexes		6	6	36	
1.4 Contention-free, non-blocking, multi-version, and read-consistent queries		1 0	6	60	By default, each insert, update, and delete statement is considered a single transaction. For contention-free, non-blocking, multi-version, and read-consistent queries you have to explicitly define transactions

Table A-2-3 Sybase Adaptive Server Enterprise Windows NT v11.5 Beta (Continued)					
1.5	Unique sequence number generation		5	3	15	Only IDENTITY column datatype - only one per table allowed
1.6	Unrestricted row-level locking without lock escalation		10	0	0	Currently in alpha test
			43	**28**	**189**	

2.0 Reliability

Not Applicable					

3.0 Maintainability

3.1	Cost Of Ownership		5	4	20	License - Minimum 8 seats - Cost $3595 Technical Support/Upgrades - Normal business hours - Ten unique problems - Technical support cost $1750 - Update subscription cost $645
3.2	Graphical installer and ease of installation		5	6	30	A known syntax error occurred but did not affect installation
3.3	Documentation		7	7	49	Dyna Text based - Capable of searching multiple documents
3.4	Systems Manager-GUI and easy to use		6	6	36	
			23	**23**	**135**	

4.0 Producibility

Not Applicable					

Table A-2-3 Sybase Adaptive Server Enterprise Windows NT v11.5 Beta (Continued)				
5.0 Capability				
5.1 Database Triggers				
5.1.1 Triggers execute on INSERT, UPDATE, or DELETE either BEFORE or AFTER operations		7	3	21	Only after the data modification statement has completed and Adaptive Server Enterprise has checked for any datatype, rule, or integrity constraint violations.
5.1.2 Triggers fire once per statement or once per row		7	3	21	Only once per statement
	14	**6**	**42**	
5.2 Declarative Integrity Constraints				
5.2.1 Cascade updates and deletes		7	0	0	None
5.2.2 Constraint checking at end of statements		7	6	42	
5.2.3 PRIMARY, FOREIGN, and UNIQUE keys, CHECK, DEFAULT, and not NULL constraints		10	6	60	You can also define a constraint called a rule. Once you create a rule, you can bind it to multiple table columns and to user datatypes.
	24	**12**	**102**	
5.3 Miscellaneous				
5.3.1 CMMS Dependencies		10	3	30	Revere product only
5.3.2 CORBA IIOP support		6	0	0	None
5.3.3 LMIS product experience		10	0	0	None
5.3.4 View support		5	6	30	

Table A-2-3 Sybase Adaptive Server Enterprise Windows NT v11.5 Beta (Continued)					
5.3.5 Extendable Object-Relational Database Architecture		10	3	30	Separate server single operational model
		41	12	90	
5.4 Object Types Support					
5.4.1 User-defined types (UDTs) support for hierarchies of types, inheritance, and Object ID reference pointers		10	0	0	Will support Java UDTs first and then SQL3 datatypes in future versions
5.4.2 Internal and external support for large objects (LOBs)		10	4	40	Support access to external data stored in separate data stores through the Component Integration Layer. Some partners store data and/or indexes inside a Sybase database, and others do not. Support for SQL3 LOBs is planned
5.4.3 User-defined functions (UDFs) with function overloading		10	0	0	Future releases will support Java UDFs returning scalar values or Java object references
		30	4	40	
5.5 Programmatic Interfaces					
5.5.1 ODBC and JDBC		10	6	60	
5.5.2 Support for 3GLs, 4GLs, and Object-oriented languages		10	6	60	
		20	12	120	

Table A-2-3 Sybase Adaptive Server Enterprise Windows NT v11.5 Beta (Continued)					
5.6 Security, Roles and Privileges					
5.6.1 Encrypted passwords with choice of internal or external user authentication		5	4	20	Yes - unable to get external user authentication to work
5.6.2 Fine-grained database privileges		6	4	24	No - only create database, default, procedure, rule, table, and view at database level
5.6.3 Hierarchical role-based security for group-level access control		6	6	36	
		17	**14**	**80**	
5.7 Stored Procedures					
5.7.1 Block structure flow control with robust exception handling, remote procedure calls (RPCs) protected by a transparent two-phase commit, and static and dynamic SQL support		10	4	40	No exception handling No dynamic SQL RPC - Programmatically through Open Server
5.7.2 Called from 3GL and other stored procedures, database triggers and SQL statements		10	6	60	

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Table A-2-3 Sybase Adaptive Server Enterprise Windows NT v11.5 Beta (Continued)					
5.7.3 Cursor variables for easy retrieval of multi-row result sets		5	6	30	
		25	16	130	
TOTALS		237	127	928	

3.4 Trade Study Assessment Legends

The DBMS trade study was scored using the following legends:

Weight Legend	
Weight	**Definition**
10 9 8	Feature required to meet functional requirements
7 6 5	Feature not needed to meet program requirements but significantly reduces cost, time, or risk
4 3 2 1	Feature not needed to meet program requirements but reduces cost, time, or risk

Score Legend	
Score	**Definition**
10	Feature Greatly Exceeds Expectations
9	
8	Feature Exceeds Expectations
7	
6	
5	Feature Meets Expectations
4	
3	
2	Feature Does Not Meet Expectations
1	
0	Feature Not Present

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4.0 Product Experience

The DBMS packages were installed and exercised at LMIS. They were all adequate for straightforward RDBMS applications. It was unfortunate that Informix did not provide their DBMS server in time for more in-depth hands on evaluation and provide enough technical support to support the evaluation.

5.0 Source Summary

The information on which the evaluation was based was drawn from a variety of sources. Material from all three vendors Web sites, technical documentation provide by the vendors, and Web sites that cater to DBMSs such as DBMS magazine Web site http://www.dbmsmag.com provided most of the technical information contained in this trade study. The vendors' sales organizations and technical personnel were also contacted. Other information was drawn from Lockheed Martin Information Systems employees and ITI-ALC Team members.

5.1 Product Data Sheets

All product data sheets collected for this trade study will be maintained in the Database Management Systems notebook.

5.2 Marketing Information

All marketing information collected for this trade study will be maintained in the Database Management Systems notebook.

5.3 Points of Contact

Company	Phone	URL
Informix Software Inc., Menlo Park, CA	415-926-6300	http://www.informix.com
Oracle Corp., Redwood Shores, CA	415-506-7000	http://www.oracle.com
Sybase Inc., Emeryville, CA	800-685-8225	http://www.sybase.com

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A-3 ELECTRONIC IDENTIFICATION TRADE STUDY

1.0 Summation

1.1 Purpose

The purpose of this trade study is to evaluate technologies and products for the ITI-ALC demonstration environment for electronic identification of individuals. Technologies and products are desired that are easy to use and acceptable to users, as well as robust against misidentifications.

1.2 Products

The methodology was to first evaluate the trade study space consisting of available technologies. The candidate technologies were gathered, and leading contenders were selected. Selected implementing packages were brought in and exercised.

Candidate technologies were picked to cover the spectrum from mature to newly emerging technologies. The technology types are:
- Password
- Signature
- Token technologies
  - Proximity card
  - Smart card
  - Swipe card
- Biometric measurement technologies
  - Voice
  - Face
  - Hand geometry
  - Fingerprint
  - Retinal vascular pattern
  - Iris pattern

1.3 Environment

The electronic identification technologies will be used both in an office setting as well as in a hangar environment. The hangar environment is the more demanding, and its users are those with which the ITI-ALC Phase 2 program will most concern itself. The hangar environment can be cramped, noisy, have temperature extremes, poorly lighted, and leave residue on users' hands. Users will commonly wear safety glasses. The technology must perform quickly enough that the ability of users swiftly to do their job is not degraded. Ideally, users should be able to identify themselves more swiftly than the current means used; however, electronic identification also brings with it the benefits of a paperless environment: easy access to data, real time updating of job completion, compact storage of

maintenance history. These benefits may outweigh a slight degradation in speed of use. The environment includes a psychological component—users might have concerns about infringement on their privacy. The use environment is taken to be collegial rather than adversarial. Users are not expected to mount malicious attacks against the recognition tool. Indeed, the current system of small stamps informally allows a small amount of latitude. A user might on occasion use someone else's stamp, say to save the need of descending from an aircraft to stamp a card or, as will certainly occasionally happen, because the stamp has been left at home. This of course is done only when the holder of the stamp is familiar with the capabilities of the using individual, or has looked over the work done.

The platforms on which these technologies will run are PCs. Potential configurations are wearable, hand-held, slate, and desktop devices. The user database is maintained on UNIX servers or Windows NT servers. The servers host the database of individuals and perform the comparison of an individual's identification information with the set of users. The demonstration environment assumes one server. The full-up environment assumes an ALC with perhaps 1500 users, three servers, and 500 client devices.

An alternative architecture briefly considered was to put template data describing one or more individuals on a portable platform. This presents significant database configuration management difficulties, and thus was rejected. It is difficult enough to maintain a database at two locations; doing so on the large number of platforms would lead to significant operability problems.

1.4 Summary of Best Candidates

Candidate Overview
Of the technologies considered, the best-rated candidate is the traditional password. Passwords provide unambiguous identification with very little data entry and transfer, the technology is very simple, and the required peripherals are an integral part of the function of all of the platforms. It is recommended that password authentication be provided even if another means for electronic identification is provided. Passwords can provide a secondary means of identification, if another primary form is not available. Passwords have a small drawback for portable computing, in that the user must either enter the password with an on-screen keyboard, which is clumsy and slow, or enter it as handwriting, which requires writing the password plainly on the screen. The latter choice risks compromising the password. The virtual keyboard is less convenient for someone who is not a typist than an ordinary keyboard, and many users would not be happy to use even the usual full keyboard.

Signature recognition has the advantage of being a totally natural action on the part of the user. It should meet with minimal resistance from users. It requires no specialized peripheral, and is unaffected by noise, lighting, or solvents. It is less unambiguous than card or password technology, however.

Of the card identification methods, the proximity card has the advantage of not needing to physically contact the reader. This provides packaging advantages. It also makes it less likely to fail than the other types of cards, since it dirt on the card will not affect it, and there is no wear on the reader.

Voice recognition provides an extremely convenient means of identification. It is hands-off and needs only a microphone, a peripheral that is fast becoming a standard item on portable computers. It is a very acceptably non-intrusive biometric, since what is measured is something that everybody offers to the world from the first "Good morning" of the day. Our experience with the technology was very good.

The other biometrics presented some difficulties. In particular, there was an immediate and distinct

resistance on the part of the mechanic users to fingerprint identification, probably because of its association with law enforcement. Hand, retina, and iris identification are also intrusive but without the law enforcement association of fingerprint identification.

Face recognition had other difficulties. The leading package, Facelt, did not reliably recognize faces unless the recognition threshold was dropped quite low. Its performance improved when it was used with a high quality camera. It was not as sensitive to camera frame rate as one would have been led to believe from the accompanying literature. Use of the high-quality ViCam camera yielded distinctly better results than were experience with the DCVC camera. The technology is very exciting, and will certainly mature, but the current state of the art is such that it is not ready for use in a Air Logistics Center as a primary form of electronic identification. It is a valuable tool when used in conjunction with other biometrics or a password, but that value is depreciated in the non-adversarial culture of an Air Logistics Center.

Voice recognition also had its difficulties. This technology was more reliable than the Facelt product. Various versions of the package were used, generally with very good results, although one version of the product reliably generated false positive returns.

Multiple Candidates

After looking at the various alternatives for electronic identification, it has become apparent that each alternative has advantages and disadvantages. Unlike some trades, it is not necessary or even desirable to limit the selection to a single choice. Different work environments favor different technologies. For engineers with a workstation, a password is a quick, familiar form of authentication. When working in a cramped cockpit, voice recognition offers the advantage of hands-off entry of authentication. Proximity cards offer the convenience of not having to remember a password, while providing the familiarity of a token for authentication.

Provision of more than one type of electronic identification has the advantage that one can back up others when they are not available. For example, if a proximity card system is used, password identification might be used when the card has been forgotten or lost. This saves the mechanic from having to get a temporary card. If voice recognition is used, a password might be used on a day when the mechanic has a sore throat. To keep hardware requirements to a minimum, if more than one form of electronic identification is used, at least one should run without any additional hardware required. This consideration mandates either a password system or a signature recognition system.

Multiple forms of identification can provide a means to enhance security. In general this is not an issue in the collegial, non-adversarial environment of the Air Logistics Centers, but it might conceivably be used for particularly critical sign-offs or for access to sensitive data, such as the audit trail for an aircraft's maintenance.

Use of more than one form of electronic identification has the disadvantage of requiring more effort to administer. The effort is, however, less than double to maintain two forms than to maintain one form. This is because only one server and user profile database would be needed. Enrollment and updating could be done for both forms at once. Moreover, the addition of the second form has the potential to alleviate administration costs of the other form. For example the availability of a password or signature system might remove the need to issue a temporary card when a mechanic forgets his card.

Overall Recommendation

The overall recommendation is to use more than one form of identification. The simplest method to implement and maintain, and the highest rated, is the traditional password. It should definitely be provided since it provides a simple backup for other methods. For the benefit of users that do not like entering alphanumeric data into a computer, signature recognition is the recommended biometric.

Communication Intelligence Corporation (CIC) is the standard vendor for this technology. Password and signature recognition have the virtue that the do not require peripherals that are not standard items on portable computers. For quick, unambiguous identification, a proximity card method is desirable. If cost and producibility constraints make it not possible to include it in the portable platforms, it could be made available at high-use locations, such as the booths in the hangar, where the readers do not have to be incorporated into the platforms. Voice recognition provides a hands-free method that uses a common peripheral on the coming generation of portable computers, a microphone. We had good experience with Nordra Technologies' Voice Print product.

1.5 Future Considerations

The electronic identification market place is dynamic. It is worthwhile to keep track of the state of the products available, since the current leading products and the condition and responsiveness of their producing companies have the potential for swift change.
The physical size of the devices that read biometrics such as fingerprint scanners or digital cameras is getting smaller, and the price of the devices is also falling. The sophistication of the algorithms is also improving, although not so rapidly. As network speed increases, more data can practically be moved about for identification, a consideration in the case of face recognition.

2.0 Trade Study Information

Methodology
The study was done in two stages. The first was to evaluate the candidate technologies. The second was to evaluate specific implementations of selected technologies.
Various technologies and products were evaluated in the context of an Air Logistics Center. The first step a broad search for identification technologies. The intent was to identify a full spectrum of technologies, from the mundane such as passwords, to the exotic, for example face recognition using infrared cameras. Supplement A-3-3 is a list of companies making the products considered.
Electronic identification has been developed for environments significantly different from that of the Air Logistics Center. In particular, many of the biometric technologies are designed to thwart concerted malicious intrusion for applications such as sensitive installations or ATM machines. These technologies are highly effective, but they are typically designed for fixed location use, making them heavy and reliant on external power. Some of them are adaptable for portable use, however, notably fingerprints, since small inexpensive fingerprints sensors that can be incorporated into a portable computer are coming on the market. These methods also have the potential to be unacceptable to users, since they intrude into the user's privacy. These technologies also provide a level of security above that needed for the Air Logistics Center application. Indeed, their very ability to unambiguously identify an individual is one reason that users might find them intrusive.
Some of the technologies are well understood by users, in particular card technologies. While the underlying technologies might vary, the method of use is familiar from the ubiquity of ATM machines. Another example of a familiar identification method is passwords. Familiarity is, however, context sensitive. For example, in the Air Logistics Center environment passwords are not universally familiar, since many of the users are not familiar with computers, particularly multi-user computers. They are, however, familiar with PIN numbers from ATM use.
The identification methods were selected for more careful analysis on the basis of two criteria. One

was "Is the method applicable to the Air Logistics Center hangar activity?" and the other was "Is it to the boundary between common and emerging technologies?" Common identification methods do not need much evaluation; cutting edge technologies such as infrared face recognition were not applicable to the ALC activity. The intent was to identify ways of performing identification that have the potential to be usefully deployed as part of the ALC work flow, with a horizon of about two years. The methods chosen to demonstrate were signature recognition, voice recognition, and face recognition.

SignOn Verify
Communications Intelligence Corporation (CIC) is a leader in pen-based technology, including signature technology recognition is. They were not receptive to providing an evaluation copy, so the technology was obtained from SignOn Systems. Their SignOn Verify package provides a development environment, along with a demonstration. We expected it to run on our slate top portable computers. After some effort trying to get it to run, we discovered, however, that the product runs only on platforms running Windows for Pen Computing. The company does not plan to port their product to Windows 95 or later operating systems. Because of this, signature recognition should be obtained from CIC if, as is likely, an operating system other than Windows for Pen Computing is selected.
SignOn Verify worked well in our experience. Signing using the stylus was natural. Enrollment is simple and quick. The API is well documented, straightforward, and provides a good spectrum of capabilities.

Voice Print
The voice recognition package chosen to work with was Voice Print from Nordra Technologies. Nordra Technologies specializes in building multi-biometric packages. Nordra Technologies was unusually responsive. The version of Voice Print used includes a licensed version of Facelt. It uses the basic Facelt technology, but with a different interface for enrollment of users.
Our experience with Voice Print was very good. It worked even when the speech was in French or Spanish. Nordra Technologies says that voice recognition works best with an independent microphone; the internal electronics of a handheld computer can affect the audio chip, injecting high frequency whine above the human hearing range that degrades voice recognition accuracy. Our experience using built-in microphones was, however, comparable to that using an external microphone. The enrollment interface is well built and easy to use.
Our experience with Nordra Technologies was also very good—they have been extremely responsive. They have experience in packaging biometrics to enhance their ease of use, including face recognition and fingerprints. They were very responsive in modifying Voice Print for ITI-ALC program demonstration needs.

Facelt
Face recognition can be done using visible or infrared radiation. The system using infrared radiation provides a biometric that is harder to spoof, but it is much more expensive and larger than the system using visible radiation. Its increased security is not needed in the Air Logistics Center environment. The product chosen was Facelt, the current industry leader. Facelt includes several refinements. The product can update the user template slowly over time to take into account changes in appearance, for example the growth of a beard. It includes the ability to save to an audit file the pictures of individuals not recognized. The package includes a well thought out enrollment sequence. Separate thresholds are user-configurable for extracting faces and for recognizing faces. Facelt can make use of small head movements to enhance its ability to extract a face from background clutter. Use of this feature is user selectable. It also can sense small facial movements, particularly eye and mouth movement, to

ensure that the face presented is not a simulacrum.

Our experience with FaceIt was mixed. The initial camera used was the Digital Vision DCVC2 camera recommended by FaceIt. The recommendation was to use a PCI video board, but that is not feasible with a portable computer. The alternative taken was to use a PCMCIA card from the camera vendor, which is less desirable, since the interface provided is not as fast. We also experienced overheating of the card and consequent unreliable performance. With this configuration, FaceIt works fairly well, but it was not quick at extracting faces, and needed a fairly low threshold before it would recognize faces reliably. We experienced better performance using a Vista Imaging ViCam camera. This camera is superior in performance to the other, but slower, since it uses a parallel port. Another advantage is that it is powered by the port and does not require an external power supply. Our experience with FaceIt was better using this camera. Its superior video quality was more than enough to overcome the disadvantage of a lower frame rate. FaceIt performance is thus sensitive to the camera characteristics. We found that face extraction was difficult in lighting that varied sharply in intensity. In particular, there were situations in which a strong light behind the face made face extraction less effective.

A drawback in our experience was that FaceIt was slow compared to other biometric technologies. We also found that its performance is very sensitive to the face extraction and recognition thresholds. This implies that management might be difficult—if the thresholds are set low enough that recognition occurs quickly and reliably, there seemed to be a significant number of false positive identifications. For some applications, this is not necessarily a drawback. One way of using biometrics is to use several, so that if one fails, another can be used. For high assurance of identification, all methods must recognize the individual; for lower levels some combination of methods can be deemed to be sufficient.

The overall impression is that face recognition is an exciting technology that does indeed work, but that it was relatively slow and unreliable in identification. Face recognition technology is advancing rapidly, as is the speed of computation, however, so that a revisit of face recognition methods in a year or two might find a package that is quick and reliable.

3.0 Trade Study Assessment Table

3.1 Evaluation Criteria

For each of the technologies and packages, a Kempner-Tregoe trade study was executed. This entails developing a set of evaluation criteria. The ITI-ALC team reviewed the criteria, and any comments were addressed by modifications to the criteria. The criteria were grouped, and each group of criteria was assigned a weight. Each criterion in each group was assigned an intra-group weight. From these, an overall weight was developed for each criterion, as described in Supplement A-3-2. This method of developing criterion weights was used so that the criteria groups would be weighted as desired. It avoids inadvertently giving a criterion group too much weight because there are many criteria in it, or giving a criterion group too little weight because there are few criteria in it. The resulting weights are those that appear in the criterion weights in Supplement A-3-1 and in Table A-3-1.

Evaluation criteria and their weights were created and evaluated from two perspectives. One was the applicability of the candidate technology or product to fulfill the demonstration needs of the ITI-ALC program over its three-year life. The other was the applicability to a production version of the capabilities demonstrated during the ITI-ALC program. The latter view was driven by the desire to make whatever is developed in the ITI-ALC program as reusable as possible. This has implications in evaluating the corporate strength of vendors, the scalability of the technology and products, and cost structure.

The evaluation criteria are described in Supplement A-3-1, with the weights assigned to each criterion. Security was removed as a criterion, since the Air Logistics Center environment is collegial, and a concerted attack on the security of the system was considered to be unlikely. Producibility is subsumed in the criteria addressing cost—all of the technologies are technically producible.

3.2 Trade Study Assessment Table

Table A-3-1 is the Trade Study Assessment Table for the products considered. This table presents the evaluation criteria, which are described in more detail in Supplement A-3-1. It gives the weight for each criterion, and a raw score for each product and criterion. From these, a weighted score for each product and criterion is derived, the product of the criterion weight and the raw product score. The weighted scores for each product are summed to provide the overall measure for the product. The rationale for the assignment of raw scores for each criterion is given below.

Table A-3-1 Electronic Identification Technology Trade Study Assessment

	Wt	Raw Product Scores Password	Signature	Proximity	Smart	Swipe	Voice	Face	Hand	Finger	Retina	Iris	Weighted Product Scores Password	Signature	Proximity	Smart	Swipe	Voice	Face	Hand	Finger	Retina	Iris
				<Cards>			<--- Biometrics --->								<-- Cards -->			<-------- Biometrics -------->					
Capabilities																							
Time to identify	3	10	9	10	10	10	6	5	8	8	7	7	30	27	30	30	30	18	15	24	24	21	21
Weight of medium	2	10	10	9	9	9	10	10	10	10	10	10	20	20	18	18	18	20	20	20	20	20	20
Weight of reader	2	10	10	5	5	5	10	6	2	5	2	2	20	20	10	10	10	20	12	4	10	4	4
Size of medium	2	10	10	8	8	8	10	10	10	10	10	10	20	20	16	16	16	20	20	20	20	20	20
Size of reader	2	10	10	5	5	5	10	6	2	5	2	2	20	20	10	10	10	20	12	4	10	4	4
Reader power use	2	10	10	8	8	8	10	8	8	8	8	8	20	20	16	16	16	20	16	16	16	16	16
Robust in hangar	2	10	10	10	7	7	8	6	10	10	6	6	20	20	20	14	14	16	12	20	20	12	12
Ease of Use																							
Learning curve	2	10	10	10	10	10	10	10	10	10	10	10	20	20	20	20	20	20	20	20	20	20	20
Convenience	6	7	10	10	7	7	10	7	1	10	1	1	42	60	60	42	42	60	42	6	60	6	6
Intrusiveness	10	10	8	10	10	10	9	9	7	5	5	5	100	80	100	100	100	90	90	70	50	50	50
Performance																							
Security	0																						
P(misidentification)	4	10	9	10	10	10	8	7	10	10	10	10	40	36	40	40	40	32	28	40	40	40	40
P(nonidentification)	4	10	9	10	10	10	8	7	10	10	10	10	40	36	40	40	40	32	28	40	40	40	40
Data volume for ID	2	10	8	10	10	10	6	4	7	7	6	6	20	16	20	20	20	12	8	14	14	12	12
Reliability																							
Technology maturity	4	10	8	10	10	10	8	7	9	9	9	9	40	32	40	40	40	32	28	36	36	36	36
Reliability	3	10	10	10	9	9	10	9	9	9	9	9	30	30	30	27	27	30	27	27	27	27	27
Installed base	3	10	7	10	9	10	7	5	6	6	5	5	30	21	30	27	30	21	15	18	18	15	15
Vendor stability	4	10	9	9	9	10	8	8	8	10	8	8	40	36	36	36	40	32	32	32	40	32	32
Cost																							
Acquisition cost	3	10	9	7	7	7	9	7	7	7	6	6	30	27	21	21	21	27	21	21	21	18	18
Maintenance cost	4	10	9	8	8	8	9	9	9	9	9	9	40	36	32	32	32	36	36	36	36	36	36
Administration																							
Ease of installation	3	10	10	8	8	8	10	8	2	8	8	8	30	30	24	24	24	30	24	6	24	24	24
Ease of management	4	10	10	8	8	8	9	8	9	9	9	9	40	40	32	32	32	36	32	36	36	36	36

Table A-3-1 Electronic Identification Technology Trade Study Assessment (Continued)

TOTAL WEIGHTED SCORES			<-- Cards -->			<-------- Biometrics -------->					
	Password	Signature	Proximity	Smart	Swipe	Voice	Face	Hand	Finger	Retina	Iris
	692	647	645	615	622	624	538	510	510	489	489

Capabilities

Time to identify

This criterion is the time it takes to complete identification from the end of user action. It does not include the time it takes to enter a password, swipe a card, or position part or all of the individual's body for biometric reading. The quickest technologies are those that need to gather the least amount of information from the individual to be identified,

Two things make for quick identification. The first is to gather little information from the ambient environment. The second is to require little processing to determine if the gathered information matches an individual's profile. The password, proximity card, smart card, and swipe card technologies all read only a few bytes of information. In the case of the card technologies, the reader reads the data information and also redundant check information, so that it may be assumed that the information was gathered without any error. That is the case, of course, for password entry, too. The match of all these must be exact with the user profile stored in the identification database; the database may be entered on a key, and thus identification can be done extremely swiftly.

The other technologies require gathering considerably more information, with attendant delays in transmitting it. Doing preprocessing at the gathering platform can minimize the amount of data to be transmitted, but it will still be larger than is the case for card or password technologies. In any case, the data gathered directly from the sensor must be processed to extract characteristic statistics. These must then be compared with the database of statistics corresponding to candidate personnel. The comparison is not immediate nor precise in general, so the comparison returns a best fit. This requires more data access and processing to find approximate fits and then the best fit than for card or password technologies.

The time to identify is longest for face recognition. This is because the processing requires two steps, both of which are complicated. The first step is extraction of the face from the background; the second is comparison of the face to the database. Of the two, the former generally takes the longest. The rapidity of face extraction depended, in our experience, primarily on the granularity of the image. Face recognition was correspondingly downrated. The other biometrics requiring feature extraction from a background, iris and retina, were downrated, although the features to be extracted are more regular, hence easier to identify. Hand and finger identification, on the other hand, do not require feature extraction from the background. Voice recognition requires a few seconds of speech.

Weight of medium

No medium is required for any of the technologies considered except for the card technologies. The weight of the cards is minimal, well under an ounce.

Weight of reader

This criterion addresses the weight of the device gathering information from the individual. The weight in question is that which is above and beyond the weight of the computing platform to which it is attached, so integrated devices that are standard on commonly available platforms have no additional weight.

A password requires no reader above and beyond the computing platform.

Signature recognition systems can be classified physically into two types. One uses a specialized pen that senses pressure and acceleration or a pressure sensitive pad. The other uses the standard pen that comes with a pen-based computing platform; this type gathers fewer data, but it also requires no hardware above and beyond that available on the basic platform. This type can also be used on mouse-based machines, say those used by engineers. We consider the second type the logical choice for ITI-ALC because it is highly desirable to minimize the amount of equipment a mechanic must carry about. Since the environment is collegial, the enhanced security provided by a larger set of measurands is not needed.

Card readers are small and can be integrated; they weigh a few ounces. Voiceprints require only a microphone, which can weigh an ounce or less and are now typically integrated into the computer, so that no additional weight can be ascribed to the microphone. Face, iris, or retina recognition requires a small video camera; such cameras are available mounted on a small card. Since cameras integrated into the platform as a standard feature are rare and likely to remain so, their weight, on the order of one or two ounces, must be included. Iris and retina identification systems are now currently oriented more toward ATM environments, where weight is not an issue, and thus are heavier. Fingerprint recognition, and card technologies require light small readers that can be integrated into a platform, while hand geometry requires a reader weighing several ounces. Commercial systems are larger.

Face, iris, or retina recognition requires a small video camera; such cameras are available mounted on a small card. Since cameras integrated into the platform as a standard feature are rare and likely to remain so, their weight, on the order of one or two ounces, must be included. It is assumed that a commercial packaging will be used rather than a custom packaging, so the weight of the camera must include a housing. A fingerprint reader is light, weighing on the order of an ounce, including an external commercial housing. The pad for hand geometry recognition requires a device the size of a hand, weighing several ounces.

Size of medium

Biometrics, passwords, signature require no medium. All of the card technologies use a medium on the order of the size of a credit card. Such small media are not inconvenient, so the technologies using them are not correspondingly downrated.

Size of reader

This criterion addresses the size of the device gathering information from the user. The weight in question is that which is above and beyond the weight of the computing platform to which it is attached, so integrated devices that are standard on commonly available platforms have no additional weight.

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this type gathers fewer data, but it also requires no hardware above and beyond that available on the basic platform. We consider the second type the logical choice for ITI-ALC because it is highly desirable to minimize the amount of equipment a mechanic must carry about. Moreover, the environment is collegial, rather than adversarial, so the reduced security provided by a larger set of measurands is not needed.

As described in the *Weight of reader* section, the signature method used is that using the computer's stylus or mouse. These are integral parts of the commercial computing platform, and thus have no additional size above the computing platform.

A small microphone is normally integrated into the new generation of portable computing platform, so its size is not an issue. Card readers are small and can be integrated; their size is normally on the order of one to four square inches. Face, iris, or retina recognition requires a small video camera; such cameras are available mounted on a small card. Some commercially available platforms are available which integrate a camera, but this is currently uncommon. A fingerprint reader can be a small device, smaller than a square inch. The pad for hand geometry recognition requires a device the size of a hand, and is consequently considerably larger.

Reader power use

It is assumed that the platform is turned on and the device and its screen are active, but that peripherals, even if they are integrated, are not active. This is because the manufacturers of platforms are responding to the limitations imposed by limited battery power by intelligently managing the activity of peripherals. The assumption is that integrated peripherals will be so managed as part of the normal system operation, but that peripherals not available as standard features of the majority of commercial platforms will require some other form of power management. There are two sources of power consumption. One is gathering the measurands; the other is transmitting them to the server that determines the identity of the user.

Use of password requires no additional power, and the data that must be transferred is very small, so power consumption is negligible. Since we assume that signatures are taken using the standard stylus, no additional power is required to gather a signature; the amount of data captured in a signature is on the order of at most a few hundred bytes, so power consumption is negligible.

Card readers use a small amount of power when they are reading a card. However, they are not integrated devices in commercially available devices. They will in general require power even when they are not reading, or else the system will require active power management, turning them on only when it is anticipated that they will be used. While this is technically feasible, it will add to the cost and complexity of the platforms, and diminish their reliability. An alternative is to require a user operation when reading the medium to turn the reader on and off. This is technically feasible, but it is inconvenient. As a result of these considerations, card readers are downgraded. The situation is comparable for cameras needed for feature recognition in images, and for fingerprint and hand configuration recognition.

Robustness in hangar

The hangar environment is the primary environment considered for this evaluation since it presents the most difficult of the environments that will be encountered and most of the users work there. Environmental challenges include the possibility that units will suffer shocks and blows during their use, lighting extremes that range from a bare bulb in the background to darkness in enclosed areas of an aircraft, ambient noise, temperature extremes, temperature variations, grease, dirt, and corrosive solvents.

Passwords must be entered via a keyboard or by handwriting. Keyboards are vulnerable to liquid spills and physical shocks. Use of a stylus requires an environment clean enough that the screen can be read and written. A signature requires a comparably clean environment. Of the card technologies, the one that is most resistant to the environment is the proximity card technology. The other card technologies are sensitive to dirt, particularly after the readers have been used for several years and the sensing elements have been subjected to wear.

Devices that require extraction of features from an image are sensitive to lighting. They are downrated, since the lighting in the hangar is highly variable, but also it may exhibit a large amount of variation in a single image since lighting inside an aircraft is likely to be poorly diffused. We have encountered difficulty in an office environment when extracting faces in lighting with large sharp variations in intensity. We expect that such lighting will present comparable difficulty in the hangar environment.

The hangar environment is often noisy, with noise from activity involving the actions of the personnel working on the aircraft as well as from equipment like fans, compressors, and other continuously running equipment. Voice recognition is correspondingly downrated. Voice recognition works best with an independent microphone; the internal electronics of a handheld computer can affect the audio chip, injecting high frequency whine that degrades voice recognition accuracy.

Ease of Use

Learning curve

This criterion addresses the ease of using the electronic identification methods. There are two types of learning required to effectively deploy an electronic identification system. One is the learning that is required for administration of the system; the other is the learning that is required from the users of the deployed system, the mechanics, planners, and engineers.

Users need to learn how to use electronic identification on a day-to-day business. They also need to know how to manage their own identification, say how to change a password, to update their signature, or to update their voice. In general, they may not need to remember how to do these rarely done activities, but they do need to know at least where to find instruction describing how to do them.

All of the forms of electronic identification require some type of administration of the database that maintains the description of the authorized users and their identities. To allow an apples-to-apples comparison, it is assumed that the data are maintained in a database whose type is the same for all technologies, say under a DBMS, or as a collection of flat files. A multimedia database is somewhat harder to maintain than a traditional text-oriented database, but the difference is small compared to other learning curve difficulties. The learning curve for maintaining the database as a database is thus assumed to be the same for all forms of electronic identification.

Passwords require no effort for the user to learn to use if data are entered with a keyboard. Even users with no typing skills can quickly learn where the few letters of their password are located. If the data are entered using handwriting, a certain amount of practice will be required to learn to write clearly enough that the handwriting will be reliably recognized. There must be a means of changing a user's password; indeed good practice requires a regular change. A simple screen for changing a password takes care of this requirement and requires minimal learning by the user. Otherwise administration of passwords is straightforward.

Entering a signature in a box with a stylus is a natural, simple action. If electronic identification is used at a platform without a stylus, two approaches can be taken. One is to provide a signature pad; the other is to use the mouse. The second approach will require a few minutes practice learning how to

sign with a mouse—it is not the natural movement of a signature using a stylus. Administration of a signature-based system is simple, although users need to have means to change their signatures, for example if someone takes on a new surname at marriage. This will occur infrequently, and can be ignored as an operational issue. Signature technology, like other biometrics, requires setting the threshold for acceptance of a signature as genuine. Users with high variability in their signature might require adjustment of the threshold. The package explored for signature recognition provides the ability to set different thresholds for different users. The face and voice recognition packages, however, provided only a single threshold for all users.

All of the card technologies require minimal training for users. Virtually everyone in the ITI-ALC target community will be familiar with ATM technology. Administration of these forms of identification requires building and issuing cards. It also requires a provision for allowing workers to sign off when their card has been forgotten or lost. Because of this, more training will be requires for the administrators.

Physical biometrics requires minimal training for users. Face, hand, finger, retina, and iris biometrics require only that the user present himself before the sensor. Voice requires only speech, a completely natural action.

Administration of the database for face and voice recognition requires tuning the recognition threshold. Alternative forms of identification must be provided when someone has a problem, say a bad cold, which temporarily alters the voice. The same is true for facial recognition if an individual has something on his face, say a bandage that makes face recognition difficult. These contingencies raise the training needs for the administrator.

Convenience

There is convenience for the user and convenience for the administrator. For this criterion, convenience for the user is by far the more important since there are so many more users than administrators. The only time when administrator convenience becomes an issue is when inconvenience in administration spills over into inconvenience for the user.

Use of a password is not very convenient on platforms that lack a keyboard. Keyboard-based password systems customarily present the typed-in password as a string of asterisks to avoid compromising the password. This is difficult to do on a pen-based system. Either the user must write the word in clear for handwriting recognition software to translate, or the user must use an on-screen keyboard, which is clumsy and slow. On keyboard-based keyboards, a password is very quick if the user can type, and quick even if typing skills are minimal, since the password will be entered repeatedly, and the user will quickly learn the location of the letters in the password. If passwords are used, the ITI-ALC environment is such that is highly desirable to allow users to choose their own password—the additional security provided by automated password selection is not needed in the collegial ITI-ALC environment, and it generates user resistance.

A signature is extremely convenient for the user of a pen-based platform—it is a natural motion. It is less so for a mouse-based platform, although it is usable.

Cards are extremely convenient to use when the user has them. The drawback in convenience is the necessity for having the card present. The cards are small enough that they can easily be carried in a pocket, and so are unlikely to be left on the hangar floor. Their main inconvenience is that they can be forgotten or mislaid. This requires a user to look about the work area for the card, to have to go somewhere to get a temporary card or to use a secondary means of identification.

Voice recognition is very convenient. Voice input is possible in cramped quarters or the dark. It requires only about 10 seconds of speech, which can easily be repeated. A real inconvenience is that caused by variability in voice, say from laryngitis or stress. This requires a secondary means of

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Voice recognition is very convenient. Voice input is possible in cramped quarters or the dark. It requires only about 10 seconds of speech, which can easily be repeated. A real inconvenience is that caused by variability in voice, say from laryngitis or stress. This requires a secondary means of identification.

Facial recognition has significant inconvenience. It requires adequate lighting, and the user must face the camera or hold the camera up in front of the user. Our experience with the technology has been that the time it takes to extract a face from the background and then to compare it with the database is considerable, on the order of a good minute or longer. In addition, the reliability of identification is not as high as other technologies, which means that more than one attempt may be required to sign off. A sharp change in appearance, such as shaving off a beard, requires building a new template for the user. This is inconvenient as well as requiring user training.

Hand shape recognition is convenient, but the size of the readers makes them inconvenient for use in the aircraft. This is also the case for the current implementations of retina and iris identification. These two technologies, like face recognition, require lighting and require the user to face the camera.

Fingerprint sensors have become inexpensive and small. They are a convenient and unambiguous means of identification. Their main drawback is sensitivity to dirty hands.

Intrusiveness

A password is non-intrusive.

A signature is somewhat intrusive, since a signature is used for purposes other than the work environment. It presents the risk, albeit small, of use for forgery in other environments.

Card technologies are non-intrusive.

Biometrics are all to some degree intrusive. The perception of intrusiveness, however, varies. For example, people in the United States are comfortable with having their picture taken, because it is done often and in many settings, and because a photograph is not an unambiguous means of identification, and because a person's face is a natural form of identification in daily social intercourse. Face recognition should thus be perceived as non-intrusive. For the same reasons, voiceprints are non-intrusive, too. Fingerprints, however, are perceived as extremely intrusive because of their association with law enforcement, their high certainty of identification, and the existence of extensive databases of fingerprints. Retina and iris identification are also intrusive because they provide a certainty of identification based on a bodily characteristic. They are not however, associated law enforcement, nor is there at this time a large database using these biometrics. Hand geometry is less intrusive as it has lower certainty of identification.

Performance

Security

This criterion has been subsumed by the next two criteria, and its weight rolled into theirs.

Probability of misidentification

A password has a probability of misidentification of 0, as do the card technologies.

Of the biometrics, finger, retina, and iris have a probability of misidentification that is essentially 0. Hand geometry also has a very low level of misidentification.

Signature identification reliability is dependent on the identification threshold used. This is true of voice

identification also, and very much so for face identification.

Probability of non-identification

A password has a probability of non-identification of 0, as do the card technologies.
Of the biometrics, finger, retina, and iris have a probability of non-identification that is essentially 0.
Hand geometry also has a very low level of misidentification.
Signature identification reliability is dependent on the identification threshold used. This is true of voice identification also, and very much so for face identification.

Data volume required

A password and the card technologies use a minimal amount of data for identification, on the order of 10 to 20 bytes.
Finger, retina, and iris identification use more data, on the order of a few hundred bytes.
Hand recognition uses a black-and-white image of the hand, 32,000 pixels, or 4,000 bytes.
Voice recognition gathers on the order of 10 seconds of speech. If we assume that statistics are extracted on the user's platform, and the comparison to the database of users is done elsewhere, the amount of data to be transferred to the identification server is on the order of a few hundred bytes.
Face recognition uses a monochromatic image of a face. If we assume that the face is extracted on the user's platform, and the comparison to the database of users is done elsewhere, the amount of data to be transferred to the identification server is on the order of 1,000 to 2,000 bytes.

Reliability

Technology maturity

Password identification and all of the card technologies are mature technologies that have been fielded in commercial systems.
Fingerprints are a mature technology. Hand, retina, and iris identification are less common.
Voice recognition is a technology that is approaching maturity. Face recognition is a still emerging technology. Its installations are not yet industrial grade.

Reliability

The main reliability issue is the sturdiness of the readers.
Password can rely on a keyboard, a device that by now has become very reliable. Otherwise, it relies on a pen, as does a signature; a pen and its screen are mature technologies and are highly reliable.
Of the card technologies, a swipe or smart card reader can go down because of wear and dirt; it is less reliable than a proximity card because it relies on physical contact.
Hand, iris, retina and face recognition use video cameras, which are reliable.

Installed base

Passwords are ubiquitous.
Swipe cards are ubiquitous, and smart cards have had substantial successful installations, for example at the Olympics, and in geographically limited commercial installations. Proximity cards are in wide use.

Fingerprint readers are common, while retina, iris, and hand installations are as yet scanty.
Voice recognition has a small installed base. Face recognition is new, and lacks a significant installed base.

Vendor stability

Vendors of password technology include all of the platform manufacturers. They are stable.
The current major developer of signature technology is CIC. There are resellers of their technology. CIC is a stable company, but there is the potential for instability in any rapidly advancing technology.
There are several swipe card companies; this is stable industry. Smart card vendors are also reasonably stable. Proximity cards are less common, but their vendors are reasonably stable.
Fingerprint recognition vendors are stable. Vendors of hand, retina, and iris identification are also reasonably stable companies, but these again are vendors in a narrow market. Only one stable company currently does Iris identification.
Voice recognition is available from different vendors, but it is a volatile area. Face recognition is available from essentially one vendor. The technology is so new that the long-term prospects of the company are unclear.

Cost

Acquisition cost

All of the technologies require some kind of a database for storing the user profiles. Some of the technologies need a larger database, but the size of the database for an Air Logistics Center is not large enough that the difference is significant in terms of storage cost.
Password cost is very low; all platforms come with the technology to implement them. It is essentially free. Implementation requires very little effort.
All of the means of biometric identification require some type of recognition software. The price of these is volatile and negotiable, making comparisons difficult. Card recognition requires only a driver for reading the card.
Signature technology is available primarily from Communication Intelligence Corporation. While some implementations require a signature pad, since the number of deployed platforms is relatively large, it is reasonable to assume that the technology to use in an Air Logistics Center is one that uses the built-in pen, reducing the cost only to software.
Card technology requires readers, whose cost will run on the order of $30 each, in addition to licensing costs.
Voice recognition requires no hardware.
Face, retina, and iris recognition all require some form of video input. Iris recognition is currently oriented towards ATM applications, with specialized video hardware. Video cameras in a housing run on the order of $100 to $200 in small quantities. A large order might provide them at a cost on the order of $50. These require integration into the computing platform, since very few platforms include a video camera as a standard option.
Hand geometry recognition and fingerprint recognition require readers. Hand geometry readers are relatively large, costing on the order of $100 per reader, while fingerprint readers should be available at about $50. Incorporation or attachment of fingerprint readers is relatively easy; hand readers are large, and incorporation would be expensive and difficult.

Maintenance cost

All of the electronic identification means share some maintenance costs—management of the user profile database, notably enrollment and disenrollment. There are, however, differences in how operation affects costs.

Maintenance of a password system is low. Provision must be made for changing the password periodically, but this function can be automated.

Signature recognition requires getting sample signatures from each user. Provision must be made for updating the signature; again this can be automated.

The card technologies all share the need for managing the physical cards. They must be purchased and distributed. There is an administrative cost to accommodate users who forget their cards. Either "loaner" cards must be stocked and managed, or a backup identification system must be used, say password.

All of the biometric means require a supervised enrollment. Hand, finger, retina, and iris identification enrollment can be done just once, since these measurands are very unlikely to change over time. Only rare events such as loss or damage of a finger or eye will change a user profile. Voices and faces, however, are apt to change abruptly. A means for updating them must be provided. The Facelt package has the capability to update appearance that changes gradually, but in general a secondary means of identification needs to be supplied for temporary changes in voice, and for abrupt changes in appearance.

Some of the biometrics, notably signature recognition, voice recognition, and face recognition, have threshold values, which must be set. A cost of using them is maintaining a person knowledgeable enough to manage the threshold so as to ensure efficient and accurate identification.

Administration

Ease of installation

When an electronic identification system using it is implemented, the majority of the software will be incorporated into a load for the individual workstations. The cost for installing it should not vary significantly among the various packages. Similarly, the server software that needs to be installed will be roughly comparable. The main difference will then be the cost of installing hardware.

Passwords and signatures require no installation.

All of the card technologies require installation of readers, or their incorporation into the platforms. Since it is a rare platform that incorporates such a reader, this is a significant cost.

Voice requires no installation if the platform has a built-in microphone, a peripheral now commonly found in portable computers. The exception might be for older engineering workstations, but these can be easily equipped with an inexpensive microphone.

Face recognition requires a video camera. This will require addition of a camera or incorporation of a camera into the platform. Integration is apt to be expensive, since an integrated camera is not a common option.

Hand recognition requires installation of hand recognition stations. These are too large to incorporate into a portable computer.

Fingerprint recognition hardware will be available at a cost and size that can be incorporated into a platform. Since commercial platforms are unlikely to include these, this would be a custom installation, with the accompanying cost.

Retina and iris recognition packages currently available are not set up to incorporate into a portable

computer. The technology could, however, be so incorporated, requiring, like face recognition, a camera as part of the portable platform.

Ease of management

In all cases, there is a need to manage the user profile database that is roughly uniform no matter what means of electronic identification is used. The main tasks here are enrollment and disenrollment of users.

Passwords need to be changed periodically. This can be automated, so that no management need be done.

Signatures may change, due to name changes, or due to changes in how an individual writes. Provision for updating a user's profile can be automated, so that no management need be done. Signature recognition requires management of the recognition threshold.

Electronic identification using cards requires managing the physical cards. Provision must be made for replacing lost or damaged cards, and for "loaners" for forgotten cards.

Voice recognition requires a provision for days when a voice changes, probably through the provision of a secondary means of identification, for example password. If password recognition is used, no management is required beyond the effort required to maintain a separate means of identification. Voice recognition requires management of the recognition threshold, both for extracting the face as well as recognizing the face.

Face recognition requires a provision for updating the user's template in the database when the user's face changes. The user can do this, if a secondary means of identification is provided to ensure that the updated template is indeed that of the user. Face recognition requires management of the recognition threshold.

Hand, finger, retina, and iris identification require little management, once they have been installed.

4.0 Product Experience

Voice Print, a voice recognition package was installed at ATL and exercised there. The FaceIt package was installed and exercised. A version of Voice Print that integrated voice and face recognition was installed and exercised. The SignOn Systems SignOn Verify signature recognition package was installed on a Telxon 1134 using Windows for Pen Computing. A smart card was exercised. Technologies in common use (e.g., password and swipe or proximity card identification) were not exercised, as they are mature and are familiar to Air Logistics Center users.

5.0 Source Summary

The information on which the evaluation was based was drawn from a variety of sources. Material from the Web sites of various vendors provided much technical information about the packages under evaluation. Journals were consulted, notably Pen Computing, but also Infoworld, PC magazine and other trade journals. Adventitious information encountered in newspapers such as the Wall Street Journal was also used. Vendors' sales organizations and technical personnel were also contacted.

Supplement A-3-1 Electronic Identification Trade Study Criteria

CRITERIA	W E I G H T	COMMENTS
Capabilities		
Time to identify	3	This time includes the time at the reader and the database. It does not include LAN time. 1 ≥ 10 seconds 10 ≤ 1 second
Weight of medium	2	1 ≥ 2 oz 10 weightless
Weight of reader	2	1 ≥ 4 oz 10 weightless
Size of medium	2	1 Barely fits in a shirt pocket 10 No medium
Size of reader	2	1 Not portable 10 Integrated with any portable computer
Power consumption of reader	2	This is power consumption attributable to the electronic ID system alone when used with portable devices. 1 ≥ 1 amp-hour in daily cycle 10 ≤ 0.1 amp-hour in daily cycle.
Robustness in hangar environment	2	The hangar has heat swings, poor lighting, and can be noisy. 1 Performs poorly in weak lighting and is temperature sensitive 10 Is unaffected.
Ease of Use		
Learning curve	2	1 The user interface is complex and requires a half a day training to use effectively. 10 Interfaces are intuitive and can be mastered in 5 minutes
Convenience	6	1 Electronic identification requires going to a workstation outside the aircraft 10 Electronic identification can be done in cramped quarters
Intrusiveness	10	1 Electronic identification uses biometric measurements and uses an active device on sensitive organs 10 Electronic identification is psychologically and physically not intrusive.

Supplement A-3-1 Electronic Identification Trade Study Criteria (Continued)

Performance		
Security	0	1 System can be compromised by unsophisticated users 10 System can be compromised by administrator only with difficulty
Probability of misidentification	4	1 $\geq .1$ 10 $\leq .001$
Probability of non-identification	4	1 $\geq .2$ 10 $\leq .01$
Data volume required for identification	2	1 $\geq 10,000$ bytes 10 ≤ 20 bytes
Reliability		
Product maturity	4	1 In beta 10 In wide use 5 years
Reliability	3	1 Most users report problems 10 No known problems
Installed base	3	1 Single user base 10 500 or more users
Vendor stability	4	1 Vendor in business less than a year 10 Vendor in business 5 years or more
Cost		
Acquisition cost	3	This is for a fully fielded system with 1000 users. 1 Over $200K 10 Free
Maintenance cost	4	This is the cost of annual licenses and upgrades 1 Over $50K 10 Free
Administration		
Ease of installation	3	1 One week or more per platform 10 One day or less per platform
Ease of management	4	1 Requires full time administrator 10 Once installed, needs no administration

Supplement A-3-2 Criterion Weight Algorithm

Consider N criterion groups, the ith with weight W_i.

Let the ith group have n_i criteria, the jth with weight w_{ij}. Let $\sigma_i = \sum_{j=1}^{n_i} w_{ij}$. Let M be the highest possible score.

Let a product score s_{ij} on the jth criterion in the ith group. The total product score is then

$$\sum_{i=1}^{N} W_i \left(M \frac{\sum_{j=1}^{n_i} w_{ij} \, s_{ij}}{\sum_{j=1}^{n_i} w_{ij} \, M} \right) = \sum_{i=1}^{N} \left(\frac{\sum_{j=1}^{n_i} W_i \, w_{ij} \, s_{ij}}{\sigma_i} \right) = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \left(\frac{W_i \, w_{ij}}{\sigma_i} \right) s_{ij}$$

The result is to weight each criterion by $\dfrac{W_i \, w_{ij}}{\sigma_i}$.

Finally, find the biggest weight $= \max_{i,j} \left(\dfrac{W_i \, w_{ij}}{\sigma_i} \right)$, call it μ, and normalize so that the corresponding criterion has weight 10.

Thus weight the jth criterion in the ith group by

$$\frac{10}{\mu} \quad \frac{W_i \, w_{ij}}{\sigma_i}$$

and round to an integer value.

This spreadsheet computes overall criterion weights from criterion group weights and criterion weights within each criterion group according to the algorithm above. It is the source of evaluation criterion weights from Table A-3-1.

max weight for normalization: 10

Criterion Groups	Criteria	Criterion group weights	intra-group weights	raw criterion weights	normalized weights
Capabilities		10			
	Language compatibility		5	1.613	5
	Platform compatibility		5	1.613	5
	Supporting product availability		4	1.290	4
	Standards based		5	1.613	5
	Flexibility		5	1.613	5
	Distribution		4	1.290	4
	Scalability		3	0.968	3
			31		
Ease of Use		4			
	Learning curve		5	2.000	7
	Implementation ease		5	2.000	7
			10		
Performance		8			
	Throughput rate		4	1.600	5
	Time to establish connection		4	1.600	5
	Maximum number of connections		4	1.600	5
	Time to bring up applications		4	1.600	5
	Memory needed		4	1.600	5
			20		
Reliability		8			
	Product maturity		4	2.286	8
	Reliability		3	1.714	6
	installed base		3	1.714	6
	Vendor stability		4	2.286	8
			14		
Cost		4			
	Acquisition cost		4	1.600	5
	Maintenance cost		6	2.400	8
			10		
Administration		6			
	Ease of installation		3	3.000	10
	Ease of management		3	3.000	10
			6	max 3.000	

Supplement A-3-3 Companies

Communication Intelligence Corporation
275 Shoreline Drive
Redwood Shores, CA 94065

Recognition Systems, Inc.
1520 Dell Avenue
Campbell, CA 95008

Identitech
100 Rialto Place
Melbourne FL 32901

Annasoft Systems
11838 Bernardo Plaza Court
San Diego CA 92128

Recognition Systems, Inc.
1520 Dell Avenue
Campbell CA 95008

Keyware Technologies
Excelsiorlaan 28-30
B-1930 Zaventem
Belgium
500 West Cummings Park
Woburn MA 01801

Visionics Corporation
1 Exchange Place
Suite 810
Jersey City, NJ 07302

App Informatik Davos
PO Box 185
7260 Davos-Dorf
Switzerland

Vasco Data Security
1919 South Highland Avenue
Suite 1180C
Lombard, IL 60148

Sensar, Incorporated
121 Whittendale Drive
Moorestown, NJ

Omron
Karasuma Street Chichijo Sagaru
Kyoto-city Kyoto 600
Japan

Security Dynamics
20 Crosby Drive
Bedford MA 0173o

Miros, Incorporated
Suite 18
572 Washington St
Wellesley, MA 02181

Nordra Technologies
PO Box 645
Andover NJ 07821

A-4. Energy Sources Trade Study

Introduction

A survey of available battery technology was conducted using both manufacturers and experimental data. Four common battery chemistries were included in the survey of technology: Lithium Ion (Table A-4-1), Zinc Air (Table A-4-2), Nickel Cadmium (Table A-4-3), and Nickel Metal-Hydride (Table A-4-4). Our purpose was to evaluate the currently available technology for use in wearable computing systems. The target system we used require 12 Volts DC, drew 3 amperes, and was required to operate at least 4 hours before changing the battery pack.

Each type of battery was rated based on the composite information of the group as a whole. The evaluation area were:

- Weight
- Capacity
- Specific Energy
- Form Factor
- Voltage
- Recharge Time
- Battery Leakage
- System Standby Power Consumption
- Shelf Life
- Operating Temperatures
- Transportability
- Safety
- Disposability
- Logistics
- Cost

Initially, we had planned for a 144-watt battery pack. After the application began to take shape and undergo preliminary testing, it became clear that half that number would suffice. It is our hope that during the final round of testing and evaluation we will be able to reduce this number once again by accurately determining the maximum reasonable length for a computer-based video conferencing session. Cost data was collected from a range of distributors of various manufacturers.

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Analysis

Our analysis indicates that the top two contenders for power solution are zinc air, and lithium Ion, based on energy capacity and mass. The zinc air cells reviewed in this study were very light, and had a high energy density. Unfortunately, they were designed for low current applications, and are incapable of supplying the current required based on our current application data. This current limit is related to the replacement rate of oxygen in the cell. The cells can become oxygen starved during high current output due to the rapid consumption of available oxygen by the electrochemical process. Zinc Air cells can be used in higher current applications, but higher current cells required more air pass through in the cells than the low current cells. Since this would require a large airflow from the environment into the battery, it is likely that the cell would become contaminated, and fail prematurely.

Though much less expensive, and recyclable, the NI-CD solutions are significantly heavier than the Li-Ion cells, as are the NI-MH units. Further, the lithium cells do not suffer from the "memory" problem NI-CD units are prone to. Li-Ion packs are typically rated for a number of cycles similar to other technologies, about 750. This is dependant on its use profile and depth of discharges.

Model Limitations and Conclusions

The lithium ion cells are clearly more expensive than the competing technologies. After eliminating the zinc air cells, the least massive competitor for the lithium ion unit is nickel cadmium, which masses 2.38 lbm, which the lithium pack is nearly 40% less massive at 1.48 lbm. There are lighter lithium ion solutions, but those cells cannot handle the continuous current rate required by our application.

There is a large tradeoff to be made between cost and mass. For this type of application it is our opinion that mass should be the dominant factor, given that the cost of the lithium pack would only represent less than 10% of the expenditure for the processing unit itself. Further, the use profile of the units has yet to be completely. It is as yet unclear what percentage of time the unit will be using its full functionality. During field-testing, we will use aggressive power management techniques, and further refine our energy model. This may reduce our energy requirements farther to a point where other technologies can be considered, and the cost of a lithium pack will be reduced yet again.

Table A-4-1 Energy Sources Trade Study: Lithium Ion					
Criteria	Rqmts	Weight	Score	Total	Comments
1.0 Performance					
Weight - The battery should be less than half of the total system weight and not more than 1 pound	Derived 311011	10	10	100	Mass of battery slightly more than target, but lightest meeting current model specification. As the model improves, the mass should decrease to meet spec.
Capacity - The system should be able to run for the duration of a job or have hot swap ability. Amperage requirements for a wearable computer typically range from 3-7 amps, so for example, for a 4-hour job; capacity for a battery needs to be between 12-28 amp hours. Batteries typically range from 50 - 2400 milliamp-hours therefore a battery pack will need to be used.	Derived 311011	10	10	100	Systems capable of meeting capacity specification.

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Table A-4-1 Energy Sources Trade Study: Lithium Ion (Continued)					
Specific Energy - The weight (W) requirements, the capacity (C) requirements, and the voltage (V) requirements determine the specific energy (SE) requirements by the equation $SE=V*C/W$. Typical specific energies for batteries range from 35 to 260. In order of lowest to highest specific energy, typical chemistries with their specific energies are NiCad (35), Lead-acid (35), Zn/alkaline/MnO (95), Li-ion (140), Zn-Air (220).	Derived 311011	10	8	80	Specific energy is higher than most systems, but not as good as the zinc-air technologies.
Form Factor - standard form factors are AAA, AA, C, D, etc. The battery chemistry and the weight together determine the volume needed for the battery. Factors to consider include ease of replacement and packing density.	Derived 311011	10	10	100	Available in a wide variety of form factors.
Voltage - The voltage should be compatible with the dominant voltage of the system components. Step up or step down DC-to-DC converters can be used for the other components. Typical voltages for wearable computer components range from 3-12 volts	Derived 311011	10	10	100	Capable of building cell pack to deliver required voltage.

Table A-4-1 Energy Sources Trade Study: Lithium Ion (Continued)					
Recharge time - This must be less than the duty cycle of the battery divided by the number of battery sets to insure ready availability. For battery chemistries that exhibit memory, the recharge time will be lengthened by a mandatory complete discharge prior to commencement of charging.	Derived 311012	8	9	72	Recharges in two hours.
Battery Leakage - This is the discharge rate under no load conditions. The lower the rate the better - a goal should be a no load discharge rate of 1000 times less than when fully operational.	Derived 311011	6	8	48	Slow leakage
System Standby Power Consumption (SSPC) (i.e. sleep mode) - should be 100 times longer than operational time. E.g. if operational time is 2 hours, then SSPC should be roughly a week.	Derived 311011	7	10	70	This is the rate at which the battery loses power in the system when it is not being used.
2.0 Reliability					
Shelf Life - at least 1 year within temperature range -30C to 50C	Derived 311011	5	3	15	Meets requirement
Operating Temperatures - at minimum should operate with -20C - +40C with negligible performance degradation	Derived 311011	10	3	30	Meets Requirement
Transportation - Are there any restrictions on modes of transportation?	Derived 311022	6	6	36	Transport as hazardous material.

Table A-4-1 Energy Sources Trade Study: Lithium Ion (Continued)					
Safety - 1) if battery is shorted will it - a) rupture? b) explode? 2) Does it vent toxic gases 3) Does it leak its contents over time?	Derived 311022	8	8	10	Leaks electrolyte if punctured
3.0 Maintainability					
Disposability - a) recyclable b) landfill safe	Derived 301201	8	5	40	Must dispose of in hazmat landfill.
4.0 Producibility					
Logistics - Are the batteries readily available? (Are they a commodity product available from several sources?)	Derived 311011	9	10	90	Available from multiple manufacturers.
Cost - For greatest economy, minimize the cost per operational usage hour. I.e. cost divided by the operating time, where maximum operating time = (cyclability * (capacity/amps). Cyclability typically ranges from 1 (for a non-rechargeable battery) to 1000.	Derived 311011	8	8	64	~$400.00
		Total:	1001		

This trade study is for energy sources for the ITI-ALC Maintenance Support Device (MSD). The goal for the MSD is sufficient capacity to operate a complete 8-hour shift with at most one battery change. For example, the system duty cycle for an inspection task may range from as low as 20% to as high as 100% but will be a function of the logistics activity (which is TBD). Similar variations are possible with other task types. The trade study criteria define a decision procedure for choosing a battery once the weight, dominant voltage, and needed capacity of the overall system is known. Hence, several criteria are described by equations rather than absolute ranges of values. Once these parameters are known with greater precision (from the concurrent work on the wearable computer trade studies), we will be able to choose/design the battery pack with greater precision.

Table A-4-2 Energy Sources Trade Study: Zinc Air

Criteria	Rqmts	Weight	Score	Total	Comments
1.0 Performance					
Weight - The battery should be less than half of the total system weight and not more than 1 pound	Derived 311011	10	10	100	least massive
Capacity - The system should be able to run for the duration of a job or have hot swap ability. Amperage requirements for a wearable computer typically range from 3-7 amps, so for example, for a 4-hour job; capacity for a battery needs to be between 12-28 amp hours. Batteries typically range from 50 - 2400 milliamp-hours therefore a battery pack will need to be used.	Derived 311011	10	10	100	Can store required energy
Specific Energy - The weight (W) requirements, the capacity (C) requirements, and the voltage (V) requirements determine the specific energy (SE) requirements by the equation $SE=V*C/W$. Typical specific energies for batteries range from 35 to 260. In order of lowest to highest specific energy, typical chemistries with their specific energies are NiCad (35), Lead-acid (35), Zn/alkaline/MnO (95), Li-ion (140), Zn-Air (220).	Derived 311011	10	10	100	Highest SE of any evaluated technology.

Table A-4-2 Energy Sources Trade Study: Zinc Air (Continued)					
Form Factor - standard form factors are AAA, AA, C, D, etc. The battery chemistry and the weight together determine the volume needed for the battery. Factors to consider include ease of replacement and packing density.	Derived 311011	**10**	7	70	Least massive cells are coin type, and would require large numbers
Voltage - The voltage should be compatible with the dominant voltage of the system components. Step up or step down DC-to-DC converters can be used for the other components. Typical voltages for wearable computer components range from 3-12 volts	Derived 311011	**10**	10	100	Capable of building cell pack to deliver required voltage.
Recharge time - This must be less than the duty cycle of the battery divided by the number of battery sets to insure ready availability. For battery chemistries that exhibit memory, the recharge time will be lengthened by a mandatory complete discharge prior to commencement of charging.	Derived 311012	**8**	1	8	Rated poorly, because the pack will need 16 hours to charge, necessitating multiple packs per unit. Also, some models not rechargeable.
Battery Leakage - This is the discharge rate under no load conditions. The lower the rate the better - a goal should be a no load discharge rate of 1000 times less than when fully operational.	Derived 311011	6	10	60	Extremely low leakage.

Table A-4-2 Energy Sources Trade Study: Zinc Air (Continued)					
System Standby Power Consumption (SSPC) (i.e. sleep mode) - should be 100 times longer than operational time. E.g. if operational time is 2 hours, then SSPC should be roughly a week.	Derived 311011	7	10	70	Meets specification.
2.0 Reliability					
Shelf Life - at least 1 year within temperature range -30C to 50C	Derived 311011	5	3	15	Meets Specification
Operating Temperatures - at minimum should operate with -20C - +40C with negligible performance degradation	Derived 311011	10	3	30	Meets Specification
Transportation - Are there any restrictions on modes of transportation?	Derived 311022	6	10	60	No Restrictions on transportation.
Safety - 1) if battery is shorted will it - a) rupture? b) explode? 2) Does it vent toxic gases 3) Does it leak its contents over time?	Derived 311022	8	10	80	Does not pose a hazard.
3.0 Maintainability					
Disposability - a) recyclable b) landfill safe	Derived 301201	8	7	56	No disposal restrictions.
4.0 Producibility					
Logistics - Are the batteries readily available? (Are they a commodity product available from several sources?)	Derived 311011	9	10	90	Available from several manufacturers

Table A-4-2 Energy Sources Trade Study: Zinc Air (Continued)					
Cost - For greatest economy, minimize the cost per operational usage hour. I.e. cost divided by the operating time, where maximum operating time = (cyclability * (capacity/amps). Cyclability typically ranges from 1 (for a non-rechargeable battery) to 1000.	Derived 311011	8	8	64	~400-500
		Total:	1003		

This trade study is for energy sources for the ITI-ALC Maintenance Support Device (MSD). The goal for the MSD is sufficient capacity to operate a complete 8-hour shift with at most one battery change. For example, the system duty cycle for an inspection task may range from as low as 20% to as high as 100% but will be a function of the logistics activity (which is TBD). Similar variations are possible with other task types. The trade study criteria define a decision procedure for choosing a battery once the weight, dominant voltage, and needed capacity of the overall system is known. Hence, several criteria are described by equations rather than absolute ranges of values. Once these parameters are known with greater precision (from the concurrent work on the wearable computer trade studies), we will be able to choose/design the battery pack with greater precision.

Table A-4-3 Energy Sources Trade Study: Nickel Cadmium					
Criteria	**Rqmts**	**Weight**	**Score**	**Total**	**Comments**
1.0 Performance					
Weight - The battery should be less than half of the total system weight and not more than 1 pound	Derived 311011	10	0	0	Packs made of this technology will not meet specified mass requirements.
Capacity - The system should be able to run for the duration of a job or have hot swap ability. Amperage requirements for a wearable computer typically range from 3-7 amps, so for example, for a 4-hour job; capacity for a battery needs to be between 12-28 amp hours. Batteries typically range from 50 - 2400 milliamp-hours therefore a battery pack will need to be used.	Derived 311011	10	10	100	Capable of holding the required energy.
Specific Energy - The weight (W) requirements, the capacity (C) requirements, and the voltage (V) requirements determine the specific energy (SE) requirements by the equation SE=V*C/W. Typical specific energies for batteries range from 35 to 260. In order of lowest to highest specific energy, typical chemistries with their specific energies are NiCad (35), Lead-acid (35), Zn/alkaline/MnO (95), Li-ion (140), Zn-Air (220).	Derived 311011	10	2	20	Extremely low.

Table A-4-3 Energy Sources Trade Study: Nickel Cadmium (Continued)					
Form Factor - standard form factors are AAA, AA, C, D, etc. The battery chemistry and the weight together determine the volume needed for the battery. Factors to consider include ease of replacement and packing density.	Derived 311011	**10**	2	20	Cells in many shapes, but too bulky in large enough numbers to meet energy requirements
Voltage - The voltage should be compatible with the dominant voltage of the system components. Step up or step down DC-to-DC converters can be used for the other components. Typical voltages for wearable computer components range from 3-12 volts	Derived 311011	**10**	10	100	Capable of building cell pack to deliver required voltage.
Recharge time - This must be less than the duty cycle of the battery divided by the number of battery sets to insure ready availability. For battery chemistries that exhibit memory, the recharge time will be lengthened by a mandatory complete discharge prior to commencement of charging.	Derived 311012	**8**	10	80	Can fast charge in 1.5 hours. By far the best technology for quick recharge.
Battery Leakage - This is the discharge rate under no load conditions. The lower the rate the better - a goal should be a no load discharge rate of 1000 times less than when fully operational.	Derived 311011	6	3	18	Higher than average leakage rate

Table A-4-3 Energy Sources Trade Study: Nickel Cadmium (Continued)					
System Standby Power Consumption (SSPC) (i.e. sleep mode) - should be 100 times longer than operational time. E.g. if operational time is 2 hours, then SSPC should be roughly a week.	Derived 311011	7	10	70	Meets requirement
2.0 Reliability					
Shelf Life - at least 1 year within temperature range -30C to 50C	Derived 311011	5	3	15	Meets specification
Operating Temperatures - at minimum should operate with -20C - +40C with negligible performance degradation	Derived 311011	10	3	30	Meets specification
Transportation - Are there any restrictions on modes of transportation?	Derived 311022	6	10	60	No restrictions on transportation.
Safety - 1) if battery is shorted will it - a) rupture? b) explode? 2) Does it vent toxic gases 3) Does it leak its contents over time?	Derived 311022	8	8	64	Can leak after extended use.
3.0 Maintainability					
Disposability - a) recyclable b) landfill safe	Derived 301201	8	10	80	Recyclable. Only chemistry, which can be recycled.
4.0 Producibility					
Logistics - Are the batteries readily available? (Are they a commodity product available from several sources?)	Derived 311011	9	10	90	Available from several manufacturers.

Table A-4-3 Energy Sources Trade Study: Nickel Cadmium (Continued)					
Cost - For greatest economy, minimize the cost per operational usage hour. I.e. cost divided by the operating time, where maximum operating time = (cyclability * (capacity/amps). Cyclability typically ranges from 1 (for a non-rechargeable battery) to 1000.	Derived 311011	8	10	80	~$250.00
		Total:	835		

This trade study is for energy sources for the ITI-ALC Maintenance Support Device (MSD). The goal for the MSD is sufficient capacity to operate a complete 8-hour shift with at most one battery change. For example, the system duty cycle for an inspection task may range from as low as 20% to as high as 100% but will be a function of the logistics activity (which is TBD). Similar variations are possible with other task types. The trade study criteria define a decision procedure for choosing a battery once the weight, dominant voltage, and needed capacity of the overall system is known. Hence, several criteria are described by equations rather than absolute ranges of values. Once these parameters are known with greater precision (from the concurrent work on the wearable computer trade studies), we will be able to choose/design the battery pack with greater precision.

Table A-4-4 Energy Sources Trade Study: Nickel Metal-Hydride					
Criteria	**Rqmts**	**Weight**	**Score**	**Total**	**Comments**
1.0 Performance					
Weight - The battery should be less than half of the total system weight and not more than 1 pound	Derived 311011	10	0	0	This technology cannot meet mass specification.
Capacity - The system should be able to run for the duration of a job or have hot swap ability. Amperage requirements for a wearable computer typically range from 3-7 amps, so for example, for a 4-hour job; capacity for a battery needs to be between 12-28 amp hours. Batteries typically range from 50 - 2400 milliamp-hours therefore a battery pack will need to be used.	Derived 311011	10	10	100	Capable of holding required amount of energy.
Specific Energy - The weight (W) requirements, the capacity (C) requirements, and the voltage (V) requirements determine the specific energy (SE) requirements by the equation SE=V*C/W. Typical specific energies for batteries range from 35 to 260. In order of lowest to highest specific energy, typical chemistries with their specific energies are NiCad (35), Lead-acid (35), Zn/alkaline/MnO (95), Li-ion (140), Zn-Air (220).	Derived 311011	10	2	20	Extremely low.

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Table A-4-4 Energy Sources Trade Study: Nickel Metal-Hydride (Continued)					
Form Factor - standard form factors are AAA, AA, C, D, etc. The battery chemistry and the weight together determine the volume needed for the battery. Factors to consider include ease of replacement and packing density.	Derived 311011	**10**	2	20	While battery comes in wide range of form factors, solution would require a large and bulky pack.
Voltage - The voltage should be compatible with the dominant voltage of the system components. Step up or step down DC-to-DC converters can be used for the other components. Typical voltages for wearable computer components range from 3-12 volts	Derived 311011	**10**	10	100	Capable of building cell pack to deliver required voltage.
Recharge time - This must be less than the duty cycle of the battery divided by the number of battery sets to insure ready availability. For battery chemistries that exhibit memory, the recharge time will be lengthened by a mandatory complete discharge prior to commencement of charging.	Derived 311012	**8**	1	8	Rated poorly, because the pack will need 16 hours to charge, necessitating multiple packs per unit.
Battery Leakage - This is the discharge rate under no load conditions. The lower the rate the better - a goal should be a no load discharge rate of 1000 times less than when fully operational.	Derived 311011	6	5	30	Poor charge retention in models investigated.

Table A-4-4 Energy Sources Trade Study: Nickel Metal-Hydride (Continued)					
System Standby Power Consumption (SSPC) (i.e. sleep mode) - should be 100 times longer than operational time. E.g. if operational time is 2 hours, then SSPC should be roughly a week.	Derived 311011	7	10	70	Meets specification.
2.0 Reliability					
Shelf Life - at least 1 year within temperature range -30C to 50C	Derived 311011	5	3	15	Meets specification.
Operating Temperatures - at minimum should operate with -20C - +40C with negligible performance degradation	Derived 311011	10	3	30	
Transportation - Are there any restrictions on modes of transportation?	Derived 311022	6	10	60	Considered dry cell. No transportation restrictions
Safety - 1) if battery is shorted will it - a) rupture? b) explode? 2) Does it vent toxic gases 3) Does it leak its contents over time?	Derived 311022	8	10	80	No listed safety hazards.
3.0 Maintainability					
Disposability - a) recyclable b) landfill safe	Derived 301201	8	7	56	No disposal restrictions. Landfill safe.

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Table A-4-4 Energy Sources Trade Study: Nickel Metal-Hydride (Continued)					
4.0 Producibility					
Logistics - Are the batteries readily available? (Are they a commodity product available from several sources?)	Derived 311011	9	10	90	Available from several manufacturers.
Cost - For greatest economy, minimize the cost per operational usage hour. I.e. cost divided by the operating time, where maximum operating time = (cyclability * (capacity/amps). Cyclability typically ranges from 1 (for a non-rechargeable battery) to 1000.	Derived 311011	8	10	80	~$275.00
		Total:	759		

This trade study is for energy sources for the ITI-ALC Maintenance Support Device (MSD). The goal for the MSD is sufficient capacity to operate a complete 8-hour shift with at most one battery change. For example, the system duty cycle for an inspection task may range from as low as 20% to as high as 100% but will be a function of the logistics activity (which is TBD). Similar variations are possible with other task types. The trade study criteria define a decision procedure for choosing a battery once the weight, dominant voltage, and needed capacity of the overall system is known. Hence, several criteria are described by equations rather than absolute ranges of values. Once these parameters are known with greater precision (from the concurrent work on the wearable computer trade studies), we will be able to choose/design the battery pack with greater precision.

A-5. Wireless Lan

1.0 Objective

A survey of the current wireless LAN technologies to be used utilized for a specific application. Particularly for an aircraft hangar environment in which it will be used to transmit text, forms, graphics, images, audio, and web browser activity. The product must have adequate bandwidth to be capable of performing all these tasks in a reasonable amount of time. Evaluation of the performance and features of these systems is an important part of the survey. Along with that, the adaptability of the system to the specific functional requirements is the other part that will be surveyed. One of the desirable features of the radios is a small form factor. This feature will allow the radio to be discretely incorporated with the hand held unit. As we will see, the form factor will play an important role in the network architecture decision. The current technologies that we will be considering are all spread spectrum radios, three of them are frequency hopping spread spectrum and one of them is a direct sequence spread spectrum radio.

The four radios that we will be surveying:
- Proxim RangeLAN2 (Table A-5-2)
- Aironet ARLAN 3000 (Table A-5-3)
- Symbol Spectrum-24 (Table A-5-4)
- Lucent WaveLAN (Table A-5-5)

The final recommendation will be based on how well these products would comply with the requirements of the wireless system in a specialized environment. Therefore, we have a matrix that outlines the most relevant characteristics and their level of importance to the specific environment and function. Each system will then be graded on each characteristic. Along with this we will be doing performance testing. Through careful analysis of the data from both parts of the survey we will get a good understanding of all the necessary elements of the ideal system for this specific function.

2.0 Procedure

Product description matrices will be filled out with data that is collected experimentally and specifications that were supplied by the manufacturer. These matrices are oriented towards the specific application of the wireless LAN. These are some of the elements in the matrix:

- Bandwidth
- EMI Interference

- EMI Immunity
- Power Management
- Power Requirements
- Resistance to Noise and Crosstalk
- Error Detection and Correction
- Adaptability
- Ease of Installation/Expandability
- Topology of Infrastructure
- Coverage
- Signal Extendibility
- Interoperability
- Software Support
- Testability
- Diversity Antenna
- Coverage
- Antenna Integration
- Radio Integration

After these matrices will be filled out, there will be a total score for each system and this score will represent how well the particular system matches the requirements for the specific application. Each system will have its own score and they can be compared with one another to determine the most suitable system.

The experimental data will be collected from running tests in two environments: in an office environment with many walls and small spaces, and in a hangar environment with open space but many large metallic objects within the space. All the experiments will be conducted with a common set of benchmarks and testing procedures. Through these experiments we will be most interested in the range, throughput, and signal strength that we will be getting from the system.

The benchmarks that we will be using are files of size 339KB, 1.3MB, 3.8MB, and 5.6MB. We will be then FTP'ing files across this wireless network. The network is composed of a PC, which is attached on a wired network, and then to the access point. The other side of the network includes a laptop with the radio card, which will be communicating with the access point and the PC ftp server. The testing will proceed by using FTP at various ranges, and then at each range we run the benchmark files.

Ranges tested:
5 ft.
25 ft.
60 ft.
~120 ft.

File sizes:
339KB
1.3MB
3.8MB
5.6MB.
The information in the matrix that is not found experimentally was obtained from the respective manufacturers. Finally each score in each category will be multiplied by the corresponding weights and the final total weighted sum will be calculated.

3.0 Analysis

Here we present our experimental results, which will show us how each system performed based on the matrix score and the throughput testing. Our analysis indicates a discrepancy between the system that scored highest in the matrix and the system that performed best in throughput. This is a very important issue because someone can incorrectly select a final product by only looking at the highest tested throughput results or just the highest score based on the matrix. The correct way to choose will be to look: at the results that the matrices produce, and the performance tests. The ideal system will be chosen after a compromise, between the matrix score and the performance results, is reached. This compromise will select the system that will most fulfill the overall requirements of the specific application.

After analyzing the final weighted score from the matrices we see that Aironet (score=1215, Figure A-5-1.) and Symbol (score=1186, Figure A-5-1.) are clear winners as the overall best products to match the requirements of this specific application (see below).
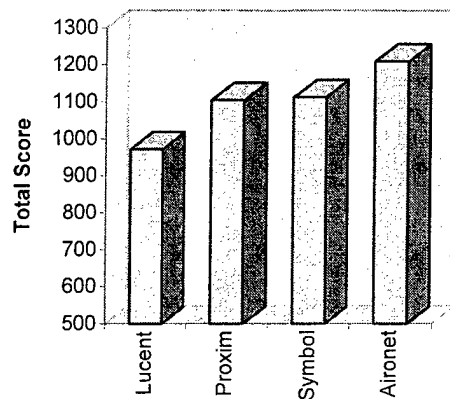
Figure A-5-1. Product Survey Matrix Weighted Scores

The performance tests show us some dramatic differences between systems. Looking at the throughput results for the office environment (Figure A-5-2.), we see that Lucent (1.19Mbps avg., 1.45Mbps max., Table A-5-1.) and Symbol (604kbps avg., 650kbps max., Table A-5-1.) are the clear winners in this category (see below). Looking at the results for the hangar environment (Figure A-5-3.), we see that Lucent (1.16Mbps avg., 1.66Mbps max. Table A-5-1.) and Symbol (628kbps avg., 650kbps max., Table A-5-1.) are clear winners in this category (see below). (Proxim hardware was not available therefore hangar environment testing was not completed).
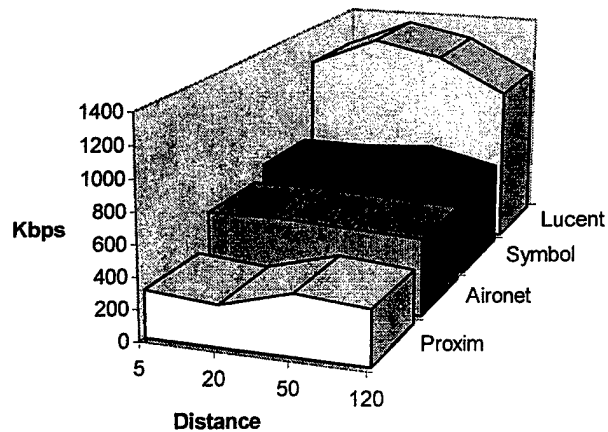
Figure A-5-2. Office Environment Testing Results
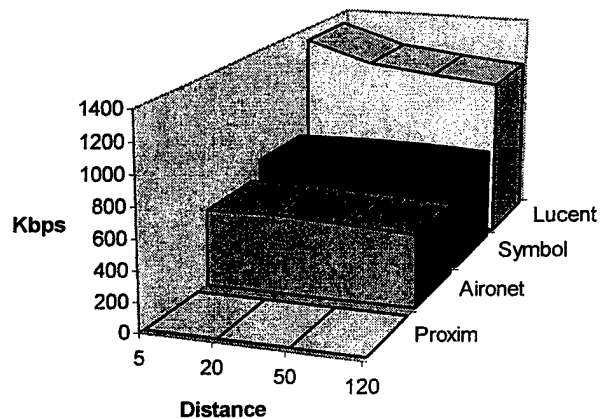
Figure A-5-3. Hangar Environment Testing Results

Some further analysis on the hangar environment testing shows some patterns as compared to the office environment tests. We noticed that the throughput for the hangar environment for the first two ranges (5ft. and 20ft.) was larger than the office environment at these ranges. This was true for the Aironet and the Symbol systems. Then for the other two ranges (50ft. and

~120ft.), the throughput for the hangar environment is lower than the office environment. This was also true for the Aironet and the Symbol systems. I would extend the same kind of results to the Proxim system. The common thread between all these systems is that they are all frequency hopping, and I believe that multipath is causing these patterns. Theoretically in an open environment the throughput should be better for the more direct line of sight, but this is only true for shorter ranges as concluded from our results. Then as the range increases multipath issues come into effect, and since these are frequency-hopping systems, it causes the degradation in throughput. In the Lucent system, which is direct sequenced, I did not notice these multipath effects.

Table A-5-1 Avg. and Max Throughput Results for Office and Hangar Environments

Throughput	Lucent	Symbol	Aironet	Proxim
Avg. Office	1.19 Mbps	604 kbps	518 kbps	321 kbps
Avg. Hangar	1.16 Mbps	628 kbps	509 kbps	–
Max Office	1.45 Mbps	650 kbps	550 kbps	390 kbps
Max Hangar	1.69 Mbps	650 kbps	530 kbps	–

4.0 Product Survey Matrices

4.1 Proxim RangeLAN2 7201 PC/ 7510 AP-2

<table>
<tr><td colspan="6">***Wireless Communication***
Table A-5-2 Trade Study: Proxim RangeLAN2 7201 PC/ 7510 AP-2</td></tr>
<tr><td>**Criteria**</td><td>**Rqmts**</td><td>**Weight**</td><td>**Score**</td><td>**Total**</td><td>**Comments**</td></tr>
<tr><td>**1.0 Performance**</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>**Bandwidth**
This is the bandwidth of the of the wireless communication channel. Higher bandwidth is better. Current best is 2.1 Mb/sec (1.1 Mb/sec actual). Bandwidths as high as 5.7 Mb and 30Mb will be available soon, There is often a trade off between coverage and bandwidth (e.g. CDPD at 19.2 has greater coverage but much lower bandwidth)</td><td>Derived 311002</td><td>10</td><td>4</td><td>40</td><td>Advertised bandwidth is:
1.6 Mbps

Actual average bandwidth from tests on file sizes from .3-5.6MB, and different ranges came out to be: 350 kbps (office). Max: 390 kbps.

Much lower bandwidth results than expected.</td></tr>
<tr><td>**EMI Interference**
The wireless LAN should not interfere with existing RF equipment in the hanger. Typical ranges for wireless is 9600 MHz-2.4 GHz. Should not have a smaller range</td><td>Derived 311002</td><td>10</td><td>5</td><td>50</td><td>We had another wireless system present and there was no noticeable sign that the Proxim was interfering with it.</td></tr>
</table>

Table A-5-2 Trade Study: Proxim RangeLAN2 7201 PC/ 7510 AP-2 (Continued)					
EMI immunity The wireless LAN should be minimally affected by existing RF environment	Derived 311002	9	7	63	The lab we were testing in had several access points that were also frequency-hopping architectures, along with a campus wide wireless LAN that is direct sequenced. We did not see any great interference that slowed down the throughput.
Power management Wireless LAN should be capable of adopting power management techniques - sleep mode, standby mode, wait mode (i.e. is there an active signal), polling mode	Derived 311002	10	7	70	Has a power management system called: Marathon Power Management. It has a doze and a sleep mode.
Power requirements (on transmitting and receiving ends) - typical values are 1.7 watts receive, 3.4 W transmit. Power management should reduce this requirement. Lower values are better.	Derived 311002	9	6	54	It draws 300 mA for transmit and 150 mA for receive. A reasonable value which is better than most other systems.
2.0 Reliability					
Resistance to noise and crosstalk Does system use direct-sequence spread spectrum (DSSS) at 915 Mhz or frequency hopping spread spectrum (FHSS) at 2.4 GHz or 5.7 GHz?	Derived 311002	9	7	63	This system is a frequency hopping spread spectrum (FHSS) at 2.4GHz. The resistance to noise and crosstalk is very good. No noticeable signs in testing.

Table A-5-2 Trade Study: Proxim RangeLAN2 7201 PC/ 7510 AP-2 (Continued)					
Error detection and correction What is the number of errors that can be corrected? Does the system employ methods such as checksum, Cycle Redundancy Coding (CRC), and automatic recovery procedures?	Derived 311002	9	5	45	This was hard to judge because there is no documentation on this but in our testing things we never encountered any corrupted data.
Adaptability The wireless network will be adequately robust to different signal and environmental changes. It should comply with requirements of appropriate regulatory authority, including FCC Part 15.247 and 15.249.	Derived 311002	8	5	40	It complies with FCC Part 15 in the US, ETSI ETS 300.328 and CE EMC-EEC in Europe.
3.0 Maintainability					
Ease of Installation/Expandability Addition of base station adapter cards and network gateway units should only require configuration of those units	Derived 311002	7	8	56	Addition of an access point only involves simple configuration, which basically sets the IP address, and as for the radio, the drivers need to be loaded. Then the system will look for its radios and start communicating
Topology of infrastructure How easily does infrastructure support mobile communication? cellular (10), or dedicated (6)	Derived 311002	9	9	81	With a single access point there is a limit to the range of operability but with multiple access points, roaming will allow you to move freely almost anywhere.

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Table A-5-2 Trade Study: Proxim RangeLAN2 7201 PC/ 7510 AP-2 (Continued)					
Coverage Do gateway units support diversity antennae, directional antennae etc.? How easily is coverage expanded through use of improved antennae technology	Derived 311002	7	8	56	No diversity antennae. Basically switching antennas and some minimal configuration on the access point will allow for greater coverage.
Signal Extendibility Can infrastructure be extended such that signals of low coverage can be brought into the wireless network?	Derived 311002	8	8	64	This is easily done with the addition of an access point at the appropriate location to pick up those specific signals.
4.0 Producability					
NA					
5.0 Capability					
Interoperability Is there IEEE 802.11 Wireless LAN support?	Derived 311002	9	5	45	There is interoperability with Wireless LAN Interoperability Forum (WLI Forum) products. There is no specific mention of IEEE 802.11 support. In testing we were not able to get it to interoperate.
Software Support Are drivers, configuration software, and benchmark software available for all targeted platforms?	Derived 311002	10	7	70	Good support of most of the major platforms: Win95, NT, DOS. No support for WinCE, Newton, Unix.

Table A-5-2 Trade Study: Proxim RangeLAN2 7201 PC/ 7510 AP-2 (Continued)					
Testability The wireless system should come with adequate benchmark software to ascertain quality of signal (strength of signal, signal degradation, coverage)	Derived 311002	9	10	90	Very good benchmarking software that made system and site surveys really clear. Good GUI's for other signal interference, signal strength, and throughput analysis.
Diversity Antennae Do radios support diversity antennae?	Derived 311002	6	0	0	There is no support for diversity antenna.
Coverage LAN needs to cover people working around plane to a local server. Currently best wireless LAN spread spectrum delivers a 600 ft radius outside, 300 ft inside dependent on layout. Repeaters can typically be used to extend signal.	Derived 311002	8	4	32	Advertised coverage with the tested snap-on antenna: 700 ft. (open) and 400 ft. (office). Test results with snap-on antenna showed coverage of: 300 ft. (open) and 80 ft. (office). Our office setting had many walls and doors.
Antenna Integration **How easily** can antenna be integrated with wearable platform?	Derived 311002	10	9	90	The antenna fits very nicely. It is just an extension of the radio's PCMCIA card. It is the width and height of PC card and maybe 1" extension beyond PC card edge.

Table A-5-2 Trade Study: Proxim RangeLAN2 7201 PC/ 7510 AP-2 (Continued)					
Radio Integration Will radio fit within wearable platform?	Derived 311002	10	9	90	The radio is a PCMCIA card, which is ideal for a wearable platform assuming it has a PCMCIA slot. The antenna has a very small form factor. Although it does protrude out of the radio edge, it can be incorporated into the package very easily.
		Total:	123	1099	

4.2 Aironet ARLAN 3000 PC3000/ AP3000-E

Wireless Communications					
Table A-5-3 Trade Study: Aironet ARLAN 3000 PC3000/ AP3000-E					
Criteria	Rqmts	Weight	Score	Total	Comments
1.0 Performance					
Bandwidth This is the bandwidth of the of the wireless communication channel. Higher bandwidth is better. Current best is 2.1 Mb/sec (1.1 Mb/sec actual). Bandwidths as high as 5.7 Mb and 30Mb will be available soon, There is often a trade off between coverage and bandwidth (e.g. CDPD at 19.2 has greater coverage but much lower bandwidth)	Derived 311002	10	6	60	Advertised bandwidth is: 1.0 Mbps Actual average bandwidth from tests on file sizes from .3-5.6MB, and different ranges came out to be: 518kbps (office), 509 kbps (hangar). Max: 550 kbps (office); 530 kbps (hangar). This bandwidth is better than expected and 50% of what is advertised is real good.
EMI Interference The wireless LAN should not interfere with existing RF equipment in the hanger. Typical ranges for wireless is 9600 MHz-2.4 GHz. Should not have a smaller range	Derived 311002	10	5	50	We had another wireless system present and there was no noticeable sign that the Aironet was interfering with it.

Table A-5-3 Trade Study: Aironet ARLAN 3000 PC3000/ AP3000-E (Continued)					
EMI immunity The wireless LAN should be minimally affected by existing RF environment.	Derived 311002	9	6	54	The lab we were testing in had several access points that were also frequency-hopping architectures, along with a campus wide wireless LAN that is direct sequenced. We did not see any great interference that slowed down the throughput.
Power management Wireless LAN should be capable of adopting power management techniques - sleep mode, standby mode, wait mode (i.e. is there an active signal), polling mode.	Derived 311002	10	6	60	It has a basic power management system. There is no mention of a sleep or doze mode. Also we noticed that our laptops battery drained really fast.
Power requirements (on transmitting and receiving ends) - typical values are 1.7 watts receive, 3.4 W transmit. Power management should reduce this requirement. Lower values are better.	Derived 311002	9	6	54	It draws 210mA on receive, and 450 mA on transmit. These numbers are in the mid-range of the systems tested, but are still good overall.
2.0 Reliability					
Resistance to noise and crosstalk Does system use direct-sequence spread spectrum (DSSS) at 915 Mhz or frequency hopping spread spectrum (FHSS) at 2.4 GHz or 5.7 GHz?	Derived 311002	9	7	63	This system is a frequency hopping spread spectrum (FHSS) at 2.4GHz. The resistance to noise and crosstalk is very good. No noticeable signs in testing.

Table A-5-3 Trade Study: Aironet ARLAN 3000 PC3000/ AP3000-E (Continued)					
Error detection and correction What is the number of errors that can be corrected? Does the system employ methods such as checksum, Cycle Redundancy Coding (CRC), and automatic recovery procedures?	Derived 311002	9	5	45	This was hard to judge because there is no documentation on this but in our testing things we never encountered any corrupted data.
Adaptability The wireless network will be adequately robust to different signal and environmental changes. It should comply with requirements of appropriate regulatory authority, including FCC Part 15.247 and 15.249.	Derived 311002	8	8	64	It complies with FCC Part 15, Subpart B, Class B and FCC Part 15.247.
3.0 Maintainability					
Ease of Installation/Expandability Addition of base station adapter cards and network gateway units should only require configuration of those units.	Derived 311002	7	8	56	Addition of an access point only involves simple configuration, which basically sets the IP address, and as for the radio, the drivers need to be loaded. Then the system will look for its radios and start communicating
Topology of infrastructure How easily does infrastructure support mobile communication? cellular (10), or dedicated (6)	Derived 311002	9	9	81	With a single access point there is a limit to the range of operability but with multiple access points, roaming will allow you to move freely almost anywhere.

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Table A-5-3 Trade Study: Aironet ARLAN 3000 PC3000/ AP3000-E (Continued)					
Coverage Do gateway units support diversity antennae, directional antennae etc.? How easily is coverage expanded through use of improved antennae technology?	Derived 311002	7	10	70	Supports diversity, omni-directional, and directional. Basically switching antennas and some minimal configuration on the access point will allow for greater coverage.
Signal Extendibility Can infrastructure be extended such that signals of low coverage can be brought into the wireless network?	Derived 311002	8	8	64	This is easily done with the addition of an access point at the appropriate location to pick up those specific signals.
4.0 Producability					
NA					
5.0 Capability					
Interoperability Is there IEEE 802.11 Wireless LAN support?	Derived 311002	9	6	54	The ARLAN 3000 series products were based on draft D5 of the IEEE 802.11 specification. Aironet says that they will comply with this standard.
Software Support Are drivers, configuration software, and benchmark software available for all targeted platforms?	Derived 311002	10	8	80	Good support of most of the major platforms: Win95, NT, DOS. OS/2. No support for WinCE, Newton.

Table A-5-3 Trade Study: Aironet ARLAN 3000 PC3000/ AP3000-E (Continued)					
Testability The wireless system should come with adequate benchmark software to ascertain quality of signal (strength of signal, signal degradation, coverage)	Derived 311002	9	8	72	Basic benchmarking software that can be accessed through the access point.
Diversity Antennae Do radios support diversity antennae?	Derived 311002	6	10	60	Supports a diversity antenna that connects externally to the radio.
Coverage LAN needs to cover people working around plane to a local server. Currently best wireless LAN spread spectrum delivers a 600 ft radius outside, 300 ft inside dependent on layout. Repeaters can typically be used to extend signal	Derived 311002	8	6	48	Advertised coverage with the tested snap-on antenna: 1000 ft. (open) and 500 ft. (office). Test results with snap-on antenna showed coverage of: 500 ft. (open) and 130 ft. (office). Our office setting had many walls and doors.
Antenna Integration How easily can antenna be integrated with wearable platform?	Derived 311002	10	9	90	The antenna fits very nicely. It is just an extension of the radio's PCMCIA card. It is the width and height of PC card and maybe 1" extension beyond PC card edge.

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Table A-5-3 Trade Study: Aironet ARLAN 3000 PC3000/ AP3000-E (Continued)					
Radio Integration Will radio fit within wearable platform?	Derived 311002	10	9	90	The radio is a PCMCIA card, which is ideal for a wearable platform assuming it has a PCMCIA slot. The antenna has a very small form factor. Although it does protrude out of the radio edge, it can be incorporated into the package very easily.
		Total:	140	1215	

4.3 Symbol Spectrum-24 LA 2400/ AP 2410

Wireless Communication **_Table A-5-4 Trade Study: Symbol Spectrum-24 LA 2400/ AP 2410_**					
Criteria	**Rqmts**	**Weight**	**Score**	**Total**	**Comments**
1.0 Performance					
Bandwidth This is the bandwidth of the of the wireless communication channel. Higher bandwidth is better. Current best is 2.1 Mb/sec (1.1 Mb/sec actual). Bandwidths as high as 5.7 Mb and 30Mb will be available soon, There is often a trade off between coverage and bandwidth (e.g. CDPD at 19.2 has greater coverage but much lower bandwidth)	Derived 311002	10	7	70	Advertised bandwidth is: 1.0 Mbps Actual average bandwidth from tests on file sizes from .3-5.6MB, and different ranges came out to be: 604 kbps (office), 628 kbps (hangar). Max: 650 kbps (office & hangar). Even though it did not reach its raw data throughput it did have an impressive throughput that is >50% of what they advertise. Did much better than expected.
EMI Interference The wireless LAN should not interfere with existing RF equipment in the hanger. Typical ranges for wireless is 9600 MHz-2.4 GHz. Should not have a smaller range	Derived 311002	10	6	60	We had another wireless system present and there was no noticeable sign that the Symbol was interfering with it.

Table A-5-4 Trade Study: Symbol Spectrum-24 LA 2400/ AP 2410 (Continued)					
EMI immunity The wireless LAN should be minimally affected by existing RF environment	Derived 311002	9	6	54	The lab we were testing in had several access points that were also frequency-hopping architectures, along with a campus wide wireless LAN that is direct sequenced. We did not see any great interference that slowed down the throughput.
Power management Wireless LAN should be capable of adopting power management techniques - sleep mode, standby mode, wait mode (i.e. is there an active signal), polling mode	Derived 311002	10	7	70	It does have a power saving mode that significantly reduces the current draw for both transmit and receive. Also in the continuous aware mode it does have a sleep mode.
Power requirements (on transmitting and receiving ends) - typical values are 1.7 watts receive, 3.4 W transmit. Power management should reduce this requirement. Lower values are better.	Derived 311002	9	5	45	For receive: 100mW: 300mA. For transmit: 100mW: 400mA These numbers are higher than the other systems. Still they are good with relation to the overall typical values.

Table A-5-4 Trade Study: Symbol Spectrum-24 LA 2400/ AP 2410 (Continued)					
2.0 Reliability					
Resistance to noise and crosstalk Does system use direct-sequence spread spectrum (DSSS) at 915 Mhz or frequency hopping spread spectrum (FHSS) at 2.4 GHz or 5.7 GHz?	Derived 311002	9	7	63	This system is a frequency hopping spread spectrum (FHSS) at 2.4GHz. The resistance to noise and crosstalk is very good. No noticeable signs in testing.
Error detection and correction What is the number of errors that can be corrected? Does the system employ methods such as checksum, Cycle Redundancy Coding (CRC), and automatic recovery procedures?	Derived 311002	9	5	45	This was hard to judge because there is no documentation on this but in our testing things we never encountered any corrupted data.
Adaptability The wireless network will be adequately robust to different signal and environmental changes. It should comply with requirements of appropriate regulatory authority, including FCC Part 15.247 and 15.249.	Derived 311002	8	8	64	It complies with FCC Part 15.247, 15.205, 15.209 in the US, ETS 300.328 in Europe.
3.0 Maintainability					
Ease of Installation/Expandability Addition of base station adapter cards and network gateway units should only require configuration of those units	Derived 311002	7	8	56	Addition of an access point only involves simple configuration, which basically sets the IP address, and as for the radio, the drivers need to be loaded. Then the system will look for its radios and start communicating

Table A-5-4 Trade Study: Symbol Spectrum-24 LA 2400/ AP 2410 (Continued)					
Topology of infrastructure How easily does infrastructure support mobile communication? cellular (10), or dedicated (6)	Derived 311002	9	7	63	With a single access point there is a limit to the range of operability but with multiple access points, roaming will allow you to move freely almost anywhere. The negative point here is that it does not support peer-to-peer communication without a micro access point.
Coverage Do gateway units support diversity antennae, directional antennae etc.? How easily is coverage expanded through use of improved antennae technology	Derived 311002	7	10	70	Directional and diversity support. Basically switching antennas and some minimal configuration on the access point will allow for greater coverage.
Signal Extendibility Can infrastructure be extended such that signals of low coverage can be brought into the wireless network?	Derived 311002	8	8	64	This is easily done with the addition of an access point at the appropriate location to pick up those specific signals. This can also be done with the addition of micro access points.
4.0 Producability					
NA					

Table A-5-4 Trade Study: Symbol Spectrum-24 LA 2400/ AP 2410 (Continued)					
5.0 Capability					
Interoperability Is there IEEE 802.11 Wireless LAN support?	Derived 311002	9	6	54	Symbol announced that they would incorporate the 802.11 standard into its Spectrum24-based wireless network product line. This system is part of the Spectrum-24 product line.
Software Support Are drivers, configuration software, and benchmark software available for all targeted platforms?	Derived 311002	10	6	60	Good support of most of the major platforms: Win95, NT, DOS. No support for WinCE.
Testability The wireless system should come with adequate benchmark software to ascertain quality of signal (strength of signal, signal degradation, coverage)	Derived 311002	9	8	72	Adequate benchmarking tools that can only be accessed through the access point and a serial cable. The software that is there tells you all the important things that you want to know.
Diversity Antennae Do radios support diversity antennae?	Derived 311002	6	10	60	Support for diversity antenna.

Table A-5-4 Trade Study: Symbol Spectrum-24 LA 2400/ AP 2410 (Continued)					
Coverage LAN needs to cover people working around plane to a local server. Currently best wireless LAN spread spectrum delivers a 600 ft radius outside, 300 ft inside dependent on layout. Repeaters can typically be used to extend signal	Derived 311002	8	7	56	Advertised coverage with the tested molded snap-on antenna: 2000 ft. (open) and 180 ft. (office). Test results with snap-on antenna showed coverage of: 900 ft. (open) and 120 ft. (office). Our office setting had many walls and doors. Since the antenna on the radio is a little larger than the others it did better in coverage and signal strength.
Antenna Integration How easily can antenna be integrated with wearable platform?	Derived 311002	10	8	80	The antenna is basically an extension of the PCMCIA card, but it does seem rather bulky. Compared to the other snap-on antennas it has a larger form factor. This antenna is not as discrete.

Table A-5-4 Trade Study: Symbol Spectrum-24 LA 2400/ AP 2410 (Continued)					
Radio Integration Will radio fit within wearable platform?	Derived 311002	10	8	80	The radio is a PCMCIA card, which is ideal for a wearable platform assuming it has a PCMCIA slot. The antenna is the only thing that might be harder to fit into the package because it is quite bulky. It seems to protrude too much from the edge of the card and the card host.
		Total:	137	1186	

4.4 Lucent WaveLAN/ WavePOINT

<table>
<tr><td colspan="6" align="center">**Wireless Communication**

Table A-5-5 Trade Study: Lucent WaveLAN/WavePOINT</td></tr>
<tr><td>Criteria</td><td>Rqmts</td><td>Weight</td><td>Score</td><td>Total</td><td>Comments</td></tr>
<tr><td>**1.0 Performance**</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>**Bandwidth**
This is the bandwidth of the of the wireless communication channel. Higher bandwidth is better. Current best is 2.1 Mb/sec (1.1 Mb/sec actual). Bandwidths as high as 5.7 Mb and 30Mb will be available soon, There is often a trade off between coverage and bandwidth (e.g. CDPD at 19.2 has greater coverage but much lower bandwidth)</td><td>Derived 311002</td><td>10</td><td>10</td><td>100</td><td>Advertised bandwidth is:
2.0 Mbps

Actual average bandwidth from tests on file sizes from .3-5.6MB, and different ranges came out to be: 1.19 Mbps (office), 1.16 Mbps (hangar). Max: 1.45 Mbps (office); 1.66 Mbps (hangar).

Throughputs of 1 Mbps are almost a minimum and at some points it was 1.66 Mbps.
These are very good results overall.</td></tr>
<tr><td>**EMI Interference**
The wireless LAN should not interfere with existing RF equipment in the hanger. Typical ranges for wireless is 9600 MHz-2.4 GHz. Should not have a smaller range</td><td>Derived 311002</td><td>10</td><td>9</td><td>90</td><td>We had another wireless system present and there was no noticeable sign that the WaveLAN was interfering with it.</td></tr>
</table>

Table A-5-5 Trade Study: Lucent WaveLAN/WavePOINT (Continued)					
EMI immunity The wireless LAN should be minimally affected by existing RF environment	Derived 311002	9	9	81	The lab we were testing in had several access points that were frequency-hopping architectures. We did not notice interference, also in the hangar environment the direct sequence was least effected while others affected by multi-path.
Power management Wireless LAN should be capable of adopting power management techniques - sleep mode, standby mode, wait mode (i.e. is there an active signal), polling mode	Derived 311002	10	6	60	It has a basic power management system. There is mention of a sleep mode.
Power requirements (on transmitting and receiving ends) - typical values are 1.7 watts receive, 3.4 W transmit. Power management should reduce this requirement. Lower values are better.	Derived 311002	9	5	45	It draws 296mA on receive, and 600 mA on transmit. These numbers are in the high-range of the systems tested, but are still good overall.
2.0 Reliability					
Resistance to noise and crosstalk Does system use direct-sequence spread spectrum (DSSS) at 915 Mhz or frequency hopping spread spectrum (FHSS) at 2.4 GHz or 5.7 GHz?	Derived 311002	9	5	45	This system is a direct sequence spread spectrum (DSSS) at 915MHz. We saw some interference.

Table A-5-5 Trade Study: Lucent WaveLAN/WavePOINT (Continued)					
Error detection and correction What is the number of errors that can be corrected? Does the system employ methods such as checksum, Cycle Redundancy Coding (CRC), and automatic recovery procedures?	Derived 311002	9	5	45	This was hard to judge because there is no documentation on this but in our testing things we never encountered any corrupted data.
Adaptability The wireless network will be adequately robust to different signal and environmental changes. It should comply with requirements of appropriate regulatory authority, including FCC Part 15.247 and 15.249.	Derived 311002	8	8	64	It complies with FCC Part 15.
3.0 Maintainability					
Ease of Installation/Expandability Addition of base station adapter cards and network gateway units should only require configuration of those units.	Derived 311002	7	8	56	Addition of an access point only involves simple configuration, which basically sets the IP address, and as for the radio, the drivers need to be loaded. Then the system will look for its radios and start communicating
Topology of infrastructure How easily does infrastructure support mobile communication? cellular (10), or dedicated (6)	Derived 311002	9	9	81	With a single access point there is a limit to the range of operability but with multiple access points, roaming will allow you to move freely almost anywhere.

Table A-5-5 Trade Study: Lucent WaveLAN/WavePOINT (Continued)					
Coverage Do gateway units support diversity antennae, directional antennae etc.? How easily is coverage expanded through use of improved antennae technology	Derived 311002	7	8	56	Omni-directional and directional. Basically switching antennas and some minimal configuration on the access point will allow for greater coverage.
Signal Extendibility Can infrastructure be extended such that signals of low coverage can be brought into the wireless network?	Derived 311002	8	8	64	This is easily done with the addition of an access point at the appropriate location to pick up those specific signals.
4.0 Producability					
NA					
5.0 Capability					
Interoperability Is there IEEE 802.11 Wireless LAN support?	Derived 311002	9	0	0	This product, which is an older generation WaveLAN, does not support this standard; there is mention that new generations will comply.
Software Support Are drivers, configuration software, and benchmark software available for all targeted platforms?	Derived 311002	10	7	70	Good support of most of the major platforms: Win95, NT, DOS.No support for WinCE, Newton.
Testability The wireless system should come with adequate benchmark software to ascertain quality of signal (strength of signal, signal degradation, coverage)	Derived 311002	9	8	72	Basic benchmarking software. Package called WaveMONITOR.

Table A-5-5 Trade Study: Lucent WaveLAN/WavePOINT (Continued)					
Diversity Antennae Do radios support diversity antennae?	Derived 311002	6	0	0	Does not support a diversity antenna.
Coverage LAN needs to cover people working around plane to a local server. Currently best wireless LAN spread spectrum delivers a 600 ft radius outside, 300 ft inside dependent on layout. Repeaters can typically be used to extend signal	Derived 311002	8	7	56	Advertised coverage with the tested antenna: 800 ft. (open) and 100 ft. (office). Test results with tested antenna showed coverage of: 400 ft. (open) and 90 ft. (office). Our office setting had many walls and doors.
Antenna Integration How easily can antenna be integrated with wearable platform?	Derived 311002	10	5	50	It is possible to integrate the antenna but it is a large form factor. It has a PCMCIA card but then there is a cable going from the card to a large 3"x5" unit which is the antenna. It might be very hard to incorporate this piece especially if the hand-held platform is small.

Table A-5-5 Trade Study: Lucent WaveLAN/WavePOINT (Continued)					
Radio Integration Will radio fit within wearable platform?	Derived 311002	10	7	70	The radio is a PCMCIA card, which is ideal for a wearable platform. The card becomes invisible and is no problem with integration just as long as there is a PCMCIA slot. The cable connecting the radio is quite bulky.
		Total:	124	1105	

5.0 Conclusion

Our experimental results and the final weighted scores need to be taken into consideration in making a final decision. Even though Lucent got the highest throughput (1.16 Mbps avg., Table A-5-1.) and Aironet got the highest score on the matrix (score=1215, Figure A-5-1.), they both did not as well in the other criteria. Symbol was the product that had the second highest score from the matrix (score=1186, Figure A-5-1.) and the second highest throughput (628 kbps avg., Table A-5-1). We would recommend the Symbol system as our number one choice because of its best overall performance and best matches the requirements of the specific implementation. The Symbol unit does well in the performance section and it also did well in having a good majority of the features that are required by this application. Our second choice would be the Aironet system with the highest score in the matrix and it was third in the throughput category. The most convenient system with respect to the integration to the wearable platform would be the Proxim. Since the Fujitsu Point 510 has a built in Proxim RangeLAN 2 radio, it has the highest degree of integration with the wearable platform. It might not be the leader in throughput but the convenience being build into a commercial product and reduced maintenance of the radio makes the Proxim a very favorable option.

It might not be clear why Symbol was chosen ahead of Aironet. If you take the placement of each product in the two categories (matrix score and throughput) they come out to a tie. The factor that made us choose Symbol was the increased throughput, because our specific functioning of the system might be required to do digital image transfer and this is where higher throughput will help.

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A-6. MIDDLEWARE TRADE STUDY

1.0 Summation

1.1 Purpose

The purpose of this trade study is to recommend a distributed infrastructure for the ITI-ALC demonstration environment that enables portions of the demonstration to talk to one another and to legacy systems. A robust environment is desired so that the products of the ITI-ALC Phase 2 effort could be applicable to a production environment.

1.2 Products

The methodology used started by considering the trade study space of available wrapper technologies available. Candidate technologies were gathered, and the leading contenders were selected. These were then further analyzed to determine which the most attractive.

Initial candidates considered included Common Object Request Broker Architecture (CORBA), Java Remote Method Invocation (RMI), the Open Software Foundation's Distributed Computing Environment (DCE), and proprietary middleware such as Prism Openbase and Microsoft's Distributed Component Object Model (DCOM). The decision was made to concentrate on emerging open technologies that will provide a wide range of capabilities. An emphasis was placed on standards-based technology with wide support. Based on these criteria, technologies were picked for further analysis. Commercially available packages within those technologies were selected for more extensive evaluation.

The initial technology downselect was made on the basis of the maturity of a technology, its prospects for the future, its capabilities, and whether it was based on an open architecture. Closed architectures like Openbase and DCOM were rejected. CORBA was considered to supersede DCE since CORBA is focused Object Oriented technology. CORBA and Java RMI were thus considered to be the leading candidates on the basis of these criteria. The CORBA specification is the product of the Object Management Group (OMG) consortium, which includes over 700 companies. It specifies a structure through which objects may be found on a wide variety of platforms and transparently executed. CORBA-compliant ORBs on the market include Digital's Object-Broker, Visigenic's VisiBroker, IBM's SOM, Sun's NEO, HP's Orb Plus, Iona Technologies' Orbix, Expersoft's Power-Broker, and ICL's DAIS. Java is a language and execution environment developed by JavaSoft, a subsidiary of Sun. Its compiled code is executed by a virtual machine, so that the same object code may be executed on a wide variety of platforms. RMI is a mechanism that allows invocation of Java objects on remote platforms.

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Both CORBA and Java RMI strongly support modern Object Oriented design and coding. The CORBA packages picked for further consideration were Iona Technologies' Orbix, Visigenics' VisiBroker, and Expersoft's CORBAplus. These were picked on the basis of market share, maturity, and technical quality.

1.3 Environment

The platforms on which these packages will run are PC clients, UNIX servers, or Windows NT servers. One interfacing legacy system runs on a UNIX platform with Oracle, others run on an IBM. The demonstration environment assumes one or two servers and at most fifteen users using at most five clients. The full-up environment assumes an ALC with perhaps 1500 users, three servers, and 500 client devices.

1.4 Summary of Best Candidate

Of the two technologies analyzed, CORBA was deemed preferable: it has a broad vendor base, a standard that is managed by a broad-based consortium by hundreds of vendors, and several years of development. Of the CORBA packages, Visigenics' VisiBroker appears to be the best candidate. It has a large installed base—it is embedded into Netscape's Communicator and Enterprise server. Our experience is that it was the easiest to use and a considerably more reliable package than Orbix. Visigenics is a stable company.

The packages not selected provide adequate tools for straightforward implementations for an ITI-ALC demonstration. As reflected in the trade study assessment table, Table 1, however, they have deficiencies that make them less desirable than VisiBroker.
Our experience with Orbix was that, while it is an adequate tool, the number of anomalies experienced during its use makes it an undesirable package, particularly since Iona's technical support organization has been unresponsive.

Expersoft's CORBAplus is a technically competent package. It does not, however, have the market share enjoyed by Orbix or VisiBroker. Expersoft is privately held, unlike Visigenics, which is listed on NASDAQ. This, coupled with the difficulty encountered in contacting their sales organization, suggests that Expersoft is less likely to have strong long-term vendor stability than Iona or Visigenics.

RMI is appealing if the sole criterion is price. It lacks, however, the breadth of industry participation of the OMG, the body that establishes the CORBA standard. The CORBA standard has been in development since 1991, Java since 1994, and Java RMI has been available only about a year. It is possible that Java RMI will become a major industry standard, but while Java packages are beginning to appear in the market place, they are not

yet as prevalent as packages in more traditional languages such as C or C++. RMI also lacks the standardized spectrum of services that are rapidly being specified by OMG and implemented by CORBA vendors.

1.5 Future Considerations

The CORBA and Java market places are very dynamic. It is worthwhile to keep track of the state of the products available, since the current leading products and the condition and responsiveness of their producing companies have the potential for swift change.

2.0 Trade Study Information

Three CORBA ORBs—Orbix, VisiBroker, CORBAplus—have been installed and exercised at the Advanced Technology Laboratories. They were generally easy to install. Of the three packages, VisiBroker was the easiest to use. Our experience with Orbix has been that there are many bugs in the implementation, and that the quality of technical support was not good. For example, the initial Orbix implementation of the Internet InterORB Protocol (IIOP) would not run at all, its successor ran but not properly, and while the current implementation is supposed to run correctly, we have not been able to verify this since another anomaly in Orbix prevents our test program from running properly.

All three CORBA implementation have industrial scale implementations—they should provide adequate throughput for an ITI-ALC demonstration or an implementation of the ITI-ALC capabilities in a production environment. Java RMI is new, so there is no installed base of large-scale production systems. It should be adequate, however, for an ITI-ALC demonstration.

3.0 Trade Study Assessment Table

3.1 Evaluation Criteria

For each of the downselected candidate packages, a Kempner-Tregoe trade study was executed. This entails developing a set of evaluation criteria. The ITI-ALC team reviewed the criteria, and their comments were addressed by modifications to the criteria. The criteria were grouped, and each group of criteria was assigned a weight. Each criterion in each group was assigned an intra-group weight. From these, an overall weight was developed for each criterion, using the algorithm described in Supplement A-6-2. This method of developing criterion weights was used so that the criteria groups would be weighted as desired. It avoids

inadvertently giving a criterion group too much weight because many there are many criteria in it, or giving a criterion group too little weight because there are few criteria in it. The resulting weights are those that appear in the criterion weights in Supplement A-6-1 and, with a modification discussed in Section 3.2, in Table A-6-1.

Evaluation criteria and their weights were created and evaluated from two perspectives. One was the applicability of the candidate technology or product to fulfill the demonstration needs of the ITI-ALC program over its three-year life. The other was the applicability to a production version of the capabilities demonstrated during the ITI-ALC program. The latter view was driven by the desire to make whatever is developed in the ITI-ALC program as reusable as possible. This has implications in evaluating the corporate strength of the vendor, the scalability of the products, and its cost structure.

The evaluation criteria are described in Supplement A-6-1, with the weights assigned to each criterion. Producibility was not included as a criterion, since it is not applicable to middleware.

3.2 Trade Study Assessment Table

Table A-6-1 is the Trade Study Assessment Table for the products. This table presents the evaluation criteria, which are described in more detail in Supplement A-6-1. It gives the weight for each criterion, and a raw score for each product and criterion. From these, a weighted score for each product and criterion is derived, the product of the criterion weight and the raw product score. The weighted scores for each product are summed to provide the overall measure for the product. The rationale for the assignment of raw scores for each criterion is given below.

Capabilities

Language compatibility
The principal languages to be used in the development of the ITI-ALC prototypes are taken to be C++ and Java. Databases may also be accessed through SQL. All three CORBA packages offer compatibility with these languages as well as others. Java RMI provides cross-platform only in a Java environment, although SunSoft will support the Internet InterORB Protocol (IIOP) to allow invoking objects in other languages. The three CORBA products accordingly received a higher raw score.

Platform compatibility
The platforms to be used for development of the ITI-ALC prototypes are taken to be a subset of UNIX, Windows NT, Windows 95, and possibly Windows CE for clients. All of the four packages evaluated are compatible with these platforms, with the possible exception of Windows CE.

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Supporting product availability

All capabilities and functionality provided by Java are available in the CORBA environment. The three CORBA packages in addition provide a suite of standardized services whose specification is managed by the OMG. The three CORBA products accordingly receive a higher raw score.

Table A-6-1 Middleware Trade Study Assessment

	Wt	Raw Product Scores				Weighted Product Scores			
		Orbix	Visi Broker	CORBA plus	Java RMI	Orbix	Visi Broker	CORBA plus	Java RMI
Capabilities									
Language compatibility	5	10	10	10	5	50	50	50	25
Platform compatibility	5	10	10	10	10	50	50	50	50
Supporting product availability	4	8	7	8	6	32	28	32	24
Standards based	5	10	10	10	7	50	50	50	35
Flexibility	5	10	8	10	7	50	40	50	35
Distribution	4	8	8	8	10	32	32	32	40
Scalability	3	9	9	9	5	27	27	27	15
Ease of Use									
Learning curve	7	6	8	7	9	42	56	49	63
implementation ease	7	7	8	7	8	49	56	49	56
Performance									
Throughput rate	25	6	8	8	8	150	200	200	200
Time to make connection		n/a	n/a	n/a	n/a				
Maximum connections		n/a	n/a	n/a	n/a				
Time to bring up applications		n/a	n/a	n/a	n/a				
Memory needed		n/a	n/a	n/a	n/a				
Reliability									
Product maturity	8	8	9	9	7	64	72	72	56
Reliability	6	8	9	9	9	48	54	54	54
Installed base	6	10	10	8	5	60	60	48	30
Vendor stabilitiy	8	10	9	7	10	80	72	56	80
Cost									
Acquisition cost	5	8	8	8	10	40	40	40	50
Maintenance cost	8	8	8	8	10	64	64	64	80
Administration									
Ease of installation	10	8	8	8	8	80	80	80	80
Ease of management	10	7	8	8	8	70	80	80	80

TOTAL WEIGHTED SCORES	1038	1111	1083	1053
	Orbix	Visi Broker	CORBA plus	Java RMI

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Standards based
The three CORBA packages are based on a standard supported by a broad consortium of commercial software houses. Java RMI is a product of a single vendor, the SunSoft subsidiary of Sun Microsystems. The three CORBA products accordingly receive a higher raw score.

Flexibility
The three CORBA packages implement the extremely flexible environment provided by the CORBA specification. They provide dynamic discovery of objects and subsequent invocation, wire-level transaction, persistent object references, and multi-language object invocation. The three CORBA products accordingly receive a higher raw score.

Distribution
The CORBA environment is more complex for implementation and operation. Java RMI accordingly receives a higher raw score.

Scalability
An implementation of the capabilities of the ITI-ALC program at an Air Logistics Center would involve 1000 to 2000 mechanics and support personnel. The CORBA packages under consideration have successful deployments this size and larger. The three CORBA products accordingly receive a higher raw score.

Ease of Use

Learning curve
Of the three CORBA implementations, the easiest to learn was VisiBroker. The constructs it provides fit well with C++ constructs. Orbix requires a more complex runtime environment, and CORBAplus makes use of macros that obscure what is happening. Java RMI is easier to learn.

Implementation ease
Implementation within the CORBA packages is easiest for VisiBroker. Orbix is the least convenient for setting up an application due to the complexity of its run time environment. CORBAplus provides powerful but somewhat arcane command line constructs. Java RMI is easy to use because of its simpler environment.

Performance

Of the detailed criteria in this category, measurements were available only for throughput. The weights of the criteria in this criterion group were correspondingly adjusted by putting all of the weight on the throughput criterion. In throughput, Orbix was noticeably slower than the other two CORBA packages.

Reliability

Product Maturity
Of the CORBA packages Orbix is the oldest. Since our experience at the Advanced Technology Laboratories with Orbix is that its releases have an untoward number of implementation anomalies, Orbix must be considered a mixture of mature and immature implementation, and is correspondingly rated lower than the other CORBA packages. Java RMI is a new product; it is in production, but it does not have the time in the market of the CORBA packages.

Product Reliability
Our experience with Orbix has been that it is unreliable. In addition to poor reliability, the Iona technical support has been unresponsive and poor, so problems with Orbix have been slow to be resolved. We have had less experience with VisiBroker, CORBAplus, and RMI, but have not experienced the frequent problems with them that we encountered with Orbix.

Installed Base
Orbix has the largest major installed base. VisiBroker also has a substantial base, and VisiBroker 2.5 is embedded in the Netscape Communicator and Enterprise server. CORBAplus has a smaller installed base, and Java RMI is a new product.

Vendor Stability
Iona Technologies is the largest CORBA package vendor and may be considered to be stable. Visigenic is a public company listed on the NASDAQ with a stable price and may be considered to be stable. Expersoft is privately held. Our experience in contacting the Expersoft marketing organization suggests that the company is undergoing some degree of reorganization and at the same time it is seeking additional capital. Its CORBAplus product is accordingly down rated. JavaSoft is a Sun Microsystems subsidiary, and may be considered very stable.

Cost

Acquisition Cost
Orbix structures its development licensing cost on the basis of development platforms and developers. The larger of the number of processors and the number of developers is the number of licenses required. Each development license on a UNIX platform costs $5000; on a Windows NT, Windows 95, Macintosh, or OS/2 it costs $2500. Run time licenses for all platforms are $100. Technical support for UNIX is $750, for Windows $400. Major upgrades are available at 20% of list price.

CORBAplus development licenses are priced separately for Java and C++. They cost $2995 per C++ UNIX seat and $1995 per C++ seat. This includes their Naming Service and Relationship Service, Life Cycle Service, and a collection of Rogue Wave tools. The current

Java development seats are free; however their OMG compliant IDL compiler supporting JDK 1.1.2 that will be available soon will be $799 per seat, for either platform. Technical support for the C++ licenses is $450 per annum for UNIX, for either platform. Technical support for the C++ licenses are $450 per annum for UNIX, $300 for NT, and for Java $150 for either platform. Run time licenses are $3595 per UNIX processor and $2595 per NT processor; support is respectively $525 and $325 per annum. Other services: Events is $895 on UNIX and $595 on NT; a partial implementation of Persistence is $1295 on UNIX and $995 on NT.

VisiBroker development seat licenses are $2995 for UNIX, $1995 for Windows NT or 95 for either C++ or Java. Seats for both are $3995 for UNIX, $2995 for Windows NT or 95. Runtime license pricing is based on the number of processors. It is $2400 per processor for UNIX and $1665 for NT.

All the CORBA vendors offer modest volume discounts.

Cost does not seem to be a discriminator among the three CORBA packages, especially on the scale of the ITI-ALC Phase 2 contract of an acquisition contract. Consider the following development and deployment models for deriving comparative cost. (Note that these are not intended to reflect the actual configuration acquired. They are for comparative purposes only.)

Using a model for the Phase 2 ITI-ALC development of 3 C++ seats on NT, 3 servers for 3 years and 5 clients, all three packages show a cost of 11 to 12 thousand dollars.

Using a model for a deployment development of 2 C++ seats and 2 Java seats, one UNIX and one NT for each, 2 UNIX servers and 2 NT servers and 20 clients, all three packages show a cost of 15 to 25 thousand dollars.

Using a model of 5 UNIX servers and 10 NT servers, all three packages show a deployment cost of about 60 thousand dollars.

Java RMI is available from JavaSoft as part of its JDK 1.1 product, which may be downloaded for free. Source code for JDK 1.1 requires a licensing fee, but should not be needed for development work. Java RMI clearly has the lowest cost, but it may not remain free indefinitely, since it is reasonable to expect that JavaSoft will in the future try to profit from its Java development, either by charging for Java or by making it necessary to buy ancillary software products.

Administration

Ease of installation
Ease of installation is roughly equivalent for all four packages.

Ease of Management

Among the CORBA packages, VisiBroker is the easiest package to use when setting up and maintaining a runtime environment. It needs only one daemon per network—any client will find it. Orbix, in comparison, requires a daemon on each node on which there exists a server object, as well as several configuration files and environment variables. CORBAplus and Java RMI ease of use are comparable to that of VisiBroker, albeit slightly less.

4.0 Product Experience

The CORBA packages were installed and exercised at ATL. They were all adequate for straightforward applications. The most striking result was the difficulty that was experienced in resolving anomalies in Orbix with Iona Technologies' technical support organization.

5.0 Source Summary

The information on which the evaluation was based was drawn from a variety of sources. Material from the Web sites of all four vendors and other vendors such as Netscape provided much technical information about the packages under evaluation. The vendors' sales organizations and technical personnel were also contacted. Other information was drawn from texts: <u>Instant CORBA</u> by Orfali, Harkey, and Edwards, and <u>CORBA Fundamentals and Programming</u>, by Siegel. The Advanced Technology Laboratories have several people conversant with CORBA that were consulted for their expertise and experience in implentation of CORBA-based systems and CORBA packages, notably Dr. Russel Noseworthy, Dr. Gautam Thaker, and Dr. Charles Peck.

Supplement A-6-1 Middleware Trade Study Criteria

CRITERIA	WEIGHT	DESCRIPTION
Language compatibility	5	1 Compatible with a single language 10 Compatible with all the languages expected to be used for ITI-ALC: C++, C, Java, Java Script, Perl, SQL
Platform compatibility	5	1 Compatible with a single platform 10 Compatible with the platforms expected to be used for ITI-ALC: Sun, Windows 95, Windows NT, Windows CE, and provides complete platform transparency
Supporting product availability	4	1 No third party vendors write for it 10 A wide variety of add-ons are available for all platforms and O/S's used in ITI-ALC
Standards based	5	1 Proprietary environment 10 Based on industry-wide standards and interoperable with comparable packages
Flexibility	5	1 The tool provides a limited set of capabilities 10 The tool provides a rich environment with a broad range of capabilities
Distribution	4	1 The tool requires substantial developed code to make work in a distributed environment 10 The tool is easy to install, implement, and operate in a distributed environment. Provisions are available for dynamic invocation of objects.

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Scalability	3	Scalability is important insofar as the ITI-ALC program must be able to do a reasonably sized demonstration, and to demonstrate an architecture that can be scaled to an operational system. The operational system, however, may of course use a different tool. 1 The tool is limited to an implementation with no more than 5 nodes or 5 users. 10 The tool is capable of handling 200 nodes with 1000 users.
Learning curve	7	1 Interfaces and underlying structures are complex and require at least a week's training and two months familiarization 10 Interfaces are intuitive and can be mastered in a day
Implementation ease	7	1 Implementation using the tool is tedious. At least 3 days are required to implement each interface, after design is complete 10 Interfaces are easy to implement. Tools provide a means to implement an interface in less than an hour.
Throughput rate	5	Varies with class of product
Time to establish connection	5	Varies with class of product
Maximum number of connections	5	Varies with class of product
Time to bring up applications	5	
Memory needed	5	1 Too large to fit on portable devices: > 5 Mb 10 Fits on all devices - < 0.5 Mb
Product maturity	8	1 in beta 10 In wide use 5 years
Reliability	6	1 Most users report problems 10 No known problems
Installed base	6	1 Single user base 10 500 or more users
Vendor stability	8	1 Vendor in business less than a year 10 Vendor in business 5 years or more

Acquisition cost	5	This includes the cost of the development seats as well as of the operational software 1 Over $200K 10 Freeware
Maintenance cost	8	This is the cost of annual licenses and upgrades 1 Over $50K 10 Freeware
Ease of installation	10	1 One week or more per platform 10 One day or less per platform
Ease of management	10	1 Requires full time administrator 10 Once installed, needs no administration

Supplement A-6-2 Criterion Weight Algorithm

Consider N criterion groups, the ith with weight W_i.

Let the ith group have n_i criteria, the jth with weight w_{ij}. Let $\sigma_i = \sum_{j=1}^{n_i} w_{ij}$. Let M be the highest possible score.

Let a product score s_{ij} on the jth criterion in the ith group. The total product score is then

$$\sum_{i=1}^{N} W_i \left(M \frac{\sum_{j=1}^{n_i} w_{ij}\, s_{ij}}{\sum_{j=1}^{n_i} w_{ij}\, M} \right) = \sum_{i=1}^{N} \left(\frac{\sum_{j=1}^{n_i} W_i\, w_{ij}\, s_{ij}}{\sigma_i} \right) = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \left(\frac{W_i\, w_{ij}}{\sigma_i} \right) s_{ij}$$

The result is to weight each criterion by $\dfrac{W_i\, w_{ij}}{\sigma_i}$.

Finally, find the biggest weight $= \max_{i,j} \left(\dfrac{W_i\, w_{ij}}{\sigma_i} \right)$, call it μ, and normalize so that the corresponding criterion has weight 10.

Thus weight the jth criterion in the ith group by

$$\frac{10}{\mu} \quad \frac{W_i\, w_{ij}}{\sigma_i}$$

and round to an integer value.

This spreadsheet computes overall criterion weights from criterion group weights
and criterion weights within each criterion group according to the algorithm above.
It is the source of evaluation criterion weights from Table A-6-1.

max weight for normalization::   10

Criterion Groups	Criteria	Criterion group weights	intra-group weights	raw criterion weights	normalized weights
Capabilities		**10**			
	Language compatibility		5	1.613	5
	Platform compatibility		5	1.613	5
	Supporting product availability		4	1.290	4
	Standards based		5	1.613	5
	Flexibility		5	1.613	5
	Distribution		4	1.290	4
	Scalability		3	0.968	3
			31		
Ease of Use		**4**			
	Learning curve		5	2.000	7
	Implementation ease		5	2.000	7
			10		
Performance		**8**			
	Throughput rate		4	1.600	5
	Time to establish connection		4	1.600	5
	Maximum number of connections		4	1.600	5
	Time to bring up applications		4	1.600	5
	Memory needed		4	1.600	5
			20		
Reliability		**8**			
	Product maturity		4	2.286	8
	Reliability		3	1.714	6
	installed base		3	1.714	6
	Vendor stability		4	2.286	8
			14		
Cost		**4**			
	Acquisition cost		4	1.600	5
	Maintenance cost		6	2.400	8
			10		
Administration		**6**			
	Ease of installation		3	3.000	10
	Ease of management		3	3.000	10
			6	max	
				3.000	

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A-7. Visualization Trade Study

1.0 Summation

1.1 Purpose

The purpose of this trade study is to recommend a visualization technology for use in developing ITI-ALC prototypes. This technology will provide functionality for mechanics to display and annotate a real-time, three-dimensional model of an airplane. The initial intended use is to allow inspectors to mark defects directly on the model (i.e. create "hotspots") to aid in communication of defect location information to planners, schedulers, and other mechanics. These recorded defects could also provide the data to construct a diagnostic database.

1.2 Products

We evaluated the following products in this trade study:

Company	Product Name
Macromedia	Director 6 Multimedia Studio (Table A-7-1)
Criterion Software	Renderware 2.1 (Table A-7-3)
Apple	QuickTime VR 2.0 and Virtual Tutor for QuickTime VR Bundle (QTVR) (Table A-7-2)
Byte by Byte	Soft F/X (Table A-7-4)

We initially considered over twenty products. Of these, we selected those that seemed to have the best ability to display a relatively complex model, hilo.3ds, on a mid-grade Pentium processor. Hilo.3ds contains 116,841 polygons. By comparison, the legacy F-15E model we received contained over 1,000,000 polygons. We also looked for the ability to include hotspots.

1.3 Environment

Of the four packages in the downselect, all four will run on Windows NT and Windows 95 platforms, although QTVR will only allow development on a Macintosh. Only Soft F/X will not run on a Macintosh system. Our demonstration environment simulated a wearable computer attempting to manipulate a detailed three-dimensional model of a helicopter. We attempted to manipulate the test model in various ways, including rotation in all dimensions and the addition and manipulation of hotspots.

1.4 Summary of Best Candidate

We cannot recommend any of the four products reviewed. See section 1.5 below for more information.

1.5 Evaluation of Other Products/Tools

None of the four technologies are adequate for our needs. All of them are too slow to be

practical for use by mechanics, and most are also unacceptable for other reasons. Director 6 Multimedia Studio has no hotspot support, and no API or SDK. Renderware 2.1 also has no hotspot support, although hotspot support could be separately coded via their API. QuickTime VR 2.0 uses an image-based representation of the airplane, which was deemed inferior to a model-based representation. It is also considerably slower than the other downselected products. Soft F/X also has no hotspot support, and the API is poor.

1.6 Future considerations

While performing this trade study, we learned that VRML (Virtual Reality Modeling Language) appears to satisfy all functional requirements. We suggest that further research be done to determine whether VRML is able to handle the requirements put forth for a visualization package. VRML is a standard accepted by many large organizations, including IBM, Microsoft, Intel, and Netscape. The following excerpt is taken from <u>The Annotated VRML 2.0 Reference Manual</u> by Rikk Carey and Gavin Bell:

> VRML, sometimes pronounced 'vermal', is an acronym for the Virtual Reality Modeling Language. Technically speaking, VRML is neither virtual reality nor a modeling language. Virtual reality typically implies an immersive 3D experience (such as a head-mounted display) and 3D input devices (such as digital gloves). VRML neither requires nor precludes immersion. Furthermore, a true modeling language would contain much richer geometric modeling primitives and mechanisms. VRML provides a bare minimum of geometric modeling features and contains numerous features far beyond the scope of a modeling language.

> So if VRML is not virtual reality or a modeling language, what is it? There are several answers to this question. At its core, VRML is simply a 3D interchange format. It defines most of the commonly used semantics found in today's 3D applications such as hierarchical transformations, light sources, viewpoints, geometry, animation, fog, material properties, and texture mapping. One of the primary goals in designing VRML was to ensure that it at least succeeded as an effective 3D file interchange format.

> A second answer is that VRML is a 3D analog to HTML. This means that VRML serves as a simple, multiplatform language for publishing 3D Web pages. This is motivated by the fact that some information is best-experienced three dimensionally, such as games, engineering and scientific visualizations, educational experiences, and architecture. Typically, these types of projects require intensive interaction, animation, and user participation and exploration beyond what is capable with a page-, text-, or image-based format (i.e., HTML).

Many of the same issues that apply to authoring, converting, and presenting IETMs via SGML also apply to 3D models and VRML. Just as authoring tools exist for IETMs, many tools are available to author VRML worlds. Conversion of legacy data is also an issue in the VRML world. For example, the Air Force has supplied the ITI-ALC project with F-15E data in the IGES format – tools must be found to convert this data to VRML. Likewise, many tools exist for presentation – often these tools are an enhancement to a standard web browser. And, just

as you can code directly in SGML, you can also code directly in VRML.

Two web sites serve as starting points for further VRML exploration: *http://www.vrml.org/* is the home page for "The VRML Consortium", the standards body dedicated to defining and promoting VRML; and *http://www.sdsc.edu/vrml/* is the home page for "The VRML Repository", a complete listing of VRML tools.

2.0 Test Data

The primary test data used was a three-dimensional attack helicopter model, hilo.3ds, containing 116,841 polygons. This is an order of magnitude less than legacy data given to us by the Air Force for their F-15E fighter jet.

3.0 Trade Study Assessment Tables

Table A-7-1 Director 6 Multimedia Studio — Trade Study Criteria					
To help in understanding these criteria, consider the three hardware platforms we are contemplating using the visualization software on: • A wearable computer displaying simplified wire-frame models. • A laptop computer on the "high-boy" displaying shaded models. • A desktop workstation displaying full three-dimensional models.					
7/8/97					
Criteria	Rqmts	Weight	Score	Total	Comments
1.0 Functional Requirements	**Note: all requirements come from the Scenario: ITI-ALC RISS section. Functional requirements are those criteria that come directly from use cases (scenarios).**				
1.1 Curved Surfaces The visualization tool must be able to draw smooth, curved surfaces to correctly model an aircraft.		10	8	80	Many programs use an insufficient number of polygons to represent a curved surface.
1.2 Hotspots The tool must be able to associate data with locations on the model. This includes the ability to add, move, and remove links		10	0	0	*Press releases suggested hotspot capabilities, which did not exist in the product.*
1.3 3-D Navigation The tool must allow navigation of smooth surfaces of the model in three dimensions.		10	10	100	Since an airplane exists in three dimensions, and is difficult to represent in only two, our tool must be able to handle three-dimensional model representations.

Table A-7-1 Director 6 Multimedia Studio (Continued)				
1.4 Manipulate Multimedia Data The tool must be able to associate data such as sound, video, digital images, and text added by the inspector with the model. The data should be stored in a format amenable to searching, presentation, and indexing.	7	0	0	
2.0 Non-functional Requirements	Note: all requirements come from the Scenario: ITI-ALC RISS section. Non-functional requirements are those criteria that are needed to support the functional requirements			
2.1 Software Architecture				
2.1.1 Client/Server Architecture The visualization should run in a client/server environment (using CGI scripts, etc.), preferably in a distributed object environment (using an API).	10	0	0	In the case of the viewing models on a wearable computer, the rendering and data manipulation needed to display the model could be performed at the server.
2.1.2 Web Interface The tool should be easily intergratable with a web browser capable of navigating 3D models (both image-based like QuickTime VR and model-based, such as VRML). By using a browser-based user interface the development time of the user interface can be significantly reduced.	5	0	0	

Table A-7-1 Director 6 Multimedia Studio (Continued)				
2.2 Development Environment				
2.2.1 Development Environment Platform Independence Any visualization code to be written should be in Java because of its high platform independence. Or, the visualization code should be accessible from Java via an API.	9	0	0	
2.3 Target Environment				
2.3.1 Target Platform Browsing The target platform must include software components that allow the browsing of image-based (QuickTime VR) or model-based (VRML) representations.	10	8	80	*Model-based representations*
2.3.2 Target Platform Authoring The target platform must include software components that allow the creation and editing of visualization models.	1	10	10	
2.3.3 Target Platform Independence. It is desirable that the tool is independent of a specific target platform	5	7	35	**Windows and Macintosh**
2.4 Performance				
2.4.1 Response Time The tool must be able to handle representing complex models quickly. Any tool with very noticeable lag (greater than 1 sec) when navigating the model must be rejected.	7	0	0	As a test model, we suggest using hilo.3ds, a 2.28 MB helicopter model, and run a visualization of it on a 486 PC with 66 MHz 16 MB of RAM. This is similar to a low-end wearable computer.

Table A-7-1 Director 6 Multimedia Studio (Continued)					
2.5 Data format					
2.5.1 Model Representation The visualization tool must use a model representation. This could be either image-based (such as QuickTime VR) or CAD-based (such as VRML).		9	10	90	The preference for either model representation should be determined during the trade study phase. **CAD-based**
3.0 Reliability					
Not applicable					
4.0 Maintainability					
Not Applicable					
5.0 Producibility					
5.1 Low Cost - The cost of the tool should be less than $1500		6	6	36	*$998*
6.0 Dependencies					
6.1 API Support by HTTP Server The HTTP server should support remote method invocation by the visualization client running on the target platform.		10	0	0	
6.2 Bandwidth The visualization server part of the tool should run on a very powerful workstation to allow for continuous smooth animations while navigating through the model		7	0	0	The server should be at least a 250 MHz Processor with 4 GB Disk storage, 256 MB RAM.
			51	431	

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Table A-7-2 QuickTime VR 2.0
Trade Study Criteria

To help in understanding these criteria, consider the three hardware platforms we are contemplating
using the visualization software on:
- A wearable computer displaying simplified wire-frame models.
- A laptop computer on the "high-boy" displaying shaded models.
- A desktop workstation displaying full three-dimensional models.

7/8/97					
Criteria	**Rqmts**	**Weight**	**Score**	**Total**	**Comments**
1.0 Functional Requirements	**Note: all requirements come from the Scenario: ITI-ALC RISS section. Functional requirements are those criteria that come directly from use cases (scenarios).**				
1.1 Curved Surfaces The visualization tool must be able to draw smooth, curved surfaces to correctly model an aircraft.		10	10	100	Many programs use an insufficient number of polygons to represent a curved surface.
1.2 Hotspots The tool must be able to associate data with locations on the model. This includes the ability to add, move, and remove links		10	10	100	
1.3 3-D Navigation The tool must allow navigation of smooth surfaces of the model in three dimensions.		10	9	90	Since an airplane exists in three dimensions, and is difficult to represent in only two, our tool must be able to handle three-dimensional model representations.
1.4 Manipulate Multimedia Data The tool must be able to associate data such as sound, video, digital images, and text added by the inspector with the model. The data should be stored in a format amenable to searching, presentation, and indexing.		7	7	49	

Table A-7-2 QuickTime VR 2.0 (Continued)					
2.0 Non-functional Requirements Note: all requirements come from the Scenario: ITI-ALC RISS section. Non-functional requirements are those criteria that are needed to support the functional requirements					
2.1 Software Architecture					
2.1.1 Client/Server Architecture The visualization should run in a client/server environment (using CGI scripts, etc.), preferably in a distributed object environment (using an API).		10	0	0	In the case of the viewing models on a wearable computer, the rendering and data manipulation needed to display the model could be performed at the server.
2.1.2 Web Interface The tool should be easily intergratable with a web browser capable of navigating 3D models (both image-based like QuickTime VR and model-based, such as VRML). By using a browser-based user interface the development time of the user interface can be significantly reduced.		5	10	50	
2.2 Development Environment					
2.2.1 Development Environment Platform Independence Any visualization code to be written should be in Java because of its high platform independence. Or, the visualization code should be accessible from Java via an API.		9	0	0	

Table A-7-2 QuickTime VR 2.0 (Continued)				
2.3 Target Environment				
2.3.1 Target Platform Browsing The target platform must include software components that allow the browsing of image-based (QuickTime VR) or model-based (VRML) representations.		10	0	0	*Image-based representation*
2.3.2 Target Platform Authoring The target platform must include software components that allow the creation and editing of visualization models.		1	10	10	**Macintosh only**
2.3.3 Target Platform Independence. It is desirable that the tool is independent of a specific target platform		5	7	35	**Windows and Macintosh**
2.4 Performance				
2.4.1 Response Time The tool must be able to handle representing complex models quickly. Any tool with very noticeable lag (greater than 1 sec) when navigating the model must be rejected.		7	0	0	As a test model, we suggest using hilo.3ds, a 2.28 MB helicopter model, and run a visualization of it on a 486 PC with 66 MHz 16 MB of RAM. This is similar to a low-end wearable computer.
2.5 Data format				
2.5.1 Model Representation The visualization tool must use a model representation. This could be either image-based (such as QuickTime VR) or CAD-based (such as VRML).		9	0	0	The preference for either model representation should be determined during the trade study phase. *Image-based.*
3.0 Reliability				
Not applicable				
4.0 Maintainability				
Not Applicable				

Table A-7-2 QuickTime VR 2.0 (Continued)					
5.0 Producibility					
5.1 Low Cost - The cost of the tool should be less than $1500		6	8	48	*$400*
6.0 Dependencies					
6.1 API Support by HTTP Server The HTTP server should support remote method invocation by the visualization client running on the target platform.		10	0	0	
6.2 Bandwidth The visualization server part of the tool should run on a very powerful workstation to allow for continuous smooth animations while navigating through the model		7	0	0	The server should be at least a 250 MHz Processor with 4 GB Disk storage, 256 MB RAM.
			71	482	

Table A-7-3 Renderware 2.1
Trade Study Criteria

To help in understanding these criteria, consider the three hardware platforms we are contemplating
using the visualization software on:
- A wearable computer displaying simplified wire-frame models.
- A laptop computer on the "high-boy" displaying shaded models.
- A desktop workstation displaying full three-dimensional models.

7/8/97					
Criteria	Rqmts	Weight	Score	Total	Comments
1.0 Functional Requirements	**Note: all requirements come from the Scenario: ITI-ALC RISS section. Functional requirements are those criteria that come directly from use cases (scenarios).**				
1.1 Curved Surfaces The visualization tool must be able to draw smooth, curved surfaces to correctly model an aircraft.		10	10	100	Many programs use an insufficient number of polygons to represent a curved surface.
1.2 Hotspots The tool must be able to associate data with locations on the model. This includes the ability to add, move, and remove links		10	2	20	*Limited support of some data linkage. Most hotspot implementation would have to be written.*
1.3 3-D Navigation The tool must allow navigation of smooth surfaces of the model in three dimensions.		10	9	90	Since an airplane exists in three dimensions, and is difficult to represent in only two, our tool must be able to handle three-dimensional model representations.
1.4 Manipulate Multimedia Data The tool must be able to associate data such as sound, video, digital images, and text added by the inspector with the model. The data should be stored in a format amenable to searching, presentation, and indexing.		7	1	7	*Format not amenable to searching, presentation, or indexing.*

Table A-7-3 Renderware 2.1 (Continued)					
2.0 Non-functional Requirements Note: all requirements come from the Scenario: ITI-ALC RISS section. Non-functional requirements are those criteria that are needed to support the functional requirements					
2.1 Software Architecture					
2.1.1 Client/Server Architecture The visualization should run in a client/server environment (using CGI scripts, etc.), preferably in a distributed object environment (using an API).		10	0	0	In the case of the viewing models on a wearable computer, the rendering and data manipulation needed to display the model could be performed at the server.
2.1.2 Web Interface The tool should be easily intergratable with a web browser capable of navigating 3D models (both image-based like QuickTime VR and model-based, such as VRML). By using a browser-based user interface the development time of the user interface can be significantly reduced.		5	0	0	
2.2 Development Environment					
2.2.1 Development Environment Platform Independence Any visualization code to be written should be in Java because of its high platform independence. Or, the visualization code should be accessible from Java via an API.		9	5	45	C++ API

Table A-7-3 Renderware 2.1 (Continued)					
2.3 Target Environment					
2.3.1 Target Platform Browsing The target platform must include software components that allow the browsing of image-based (QuickTime VR) or model-based (VRML) representations.		10	10	100	*Model-based representation*
2.3.2 Target Platform Authoring The target platform must include software components that allow the creation and editing of visualization models.		1	10	10	
2.3.3 Target Platform Independence. It is desirable that the tool is independent of a specific target platform		5	7	35	**Windows and Macintosh**
2.4 Performance					
2.4.1 Response Time The tool must be able to handle representing complex models quickly. Any tool with very noticeable lag (greater than 1 sec) when navigating the model must be rejected.		7	0	0	As a test model, we suggest using hilo.3ds, a 2.28 MB helicopter model, and run a visualization of it on a 486 PC with 66 MHz 16 MB of RAM. This is similar to a low-end wearable computer.
2.5 Data format					
2.5.1 Model Representation The visualization tool must use a model representation. This could be either image-based (such as QuickTime VR) or CAD-based (such as VRML).		9	10	90	The preference for either model representation should be determined during the trade study phase. *Model-based.*
3.0 Reliability					
Not applicable					
4.0 Maintainability					
Not Applicable					
5.0 Producibility					
5.1 Low Cost - The cost of the tool should be less than $1500		6	0	0	**Upwards of $10,000**

Table A-7-3 Renderware 2.1 (Continued)					
6.0 Dependencies					
6.1 API Support by HTTP Server The HTTP server should support remote method invocation by the visualization client running on the target platform.		10	0	0	
6.2 Bandwidth The visualization server part of the tool should run on a very powerful workstation to allow for continuous smooth animations while navigating through the model		7	0	0	The server should be at least a 250 MHz Processor with 4 GB Disk storage, 256 MB RAM.
			64	**497**	

Table A-7-4 Soft F/X					
Trade Study Criteria					
To help in understanding these criteria, consider the three hardware platforms we are contemplating using the visualization software on: • A wearable computer displaying simplified wire-frame models. • A laptop computer on the "high-boy" displaying shaded models. • A desktop workstation displaying full three-dimensional models.					
7/8/97					
Criteria	**Rqmts**	**Weight**	**Score**	**Total**	**Comments**
1.0 Functional Requirements	**Note: all requirements come from the Scenario: ITI-ALC RISS section. Functional requirements are those criteria that come directly from use cases (scenarios).**				
1.1 Curved Surfaces The visualization tool must be able to draw smooth, curved surfaces to correctly model an aircraft.		10	10	100	Many programs use an insufficient number of polygons to represent a curved surface.
1.2 Hotspots The tool must be able to associate data with locations on the model. This includes the ability to add, move, and remove links		10	0	0	_Hotspot support must be fully written by us through the API._

Table A-7-4 Soft F/X (Continued)				
1.3 3-D Navigation The tool must allow navigation of smooth surfaces of the model in three dimensions.	10	10	100	Since an airplane exists in three dimensions, and is difficult to represent in only two, our tool must be able to handle three-dimensional model representations.
1.4 Manipulate Multimedia Data The tool must be able to associate data such as sound, video, digital images, and text added by the inspector with the model. The data should be stored in a format amenable to searching, presentation, and indexing.	7	0	0	
2.0 Non-functional Requirements ALC	**Note: all requirements come from the Scenario: ITI-RISS section. Non-functional requirements are those criteria that are needed to support the functional requirements**			
2.1 Software Architecture				
2.1.1 Client/Server Architecture The visualization should run in a client/server environment (using CGI scripts, etc.), preferably in a distributed object environment (using an API).	10 .	0	0	In the case of the viewing models on a wearable computer, the rendering and data manipulation needed to display the model could be performed at the server.

Table A-7-4 Soft F/X (Continued)				
2.1.2 Web Interface The tool should be easily intergratable with a web browser capable of navigating 3D models (both image-based like QuickTime VR and model-based, such as VRML). By using a browser-based user interface the development time of the user interface can be significantly reduced.		5	0	0	
2.2 Development Environment				
2.2.1 Development Environment Platform Independence Any visualization code to be written should be in Java because of its high platform independence. Or, the visualization code should be accessible from Java via an API.		9	5	45	C++ API
2.3 Target Environment				
2.3.1 Target Platform Browsing The target platform must include software components that allow the browsing of image-based (QuickTime VR) or model-based (VRML) representations.		10	10	100	*Model-based representation*
2.3.2 Target Platform Authoring The target platform must include software components that allow the creation and editing of visualization models.		1	10	10	
2.3.3 Target Platform Independence. It is desirable that the tool is independent of a specific target platform		5	5	25	**Windows**

Table A-7-4 Soft F/X (Continued)					
2.4 Performance					
2.4.1 Response Time The tool must be able to handle representing complex models quickly. Any tool with very noticeable lag (greater than 1 sec) when navigating the model must be rejected.		7	0	0	As a test model, we suggest using hilo.3ds, a 2.28 MB helicopter model, and run a visualization of it on a 486 PC with 66 MHz 16 MB of RAM. This is similar to a low-end wearable computer.
2.5 Data format					
2.5.1 Model Representation The visualization tool must use a model representation. This could be either image-based (such as QuickTime VR) or CAD-based (such as VRML).		9	10	90	The preference for either model representation should be determined during the trade study phase. *Model-based.*
3.0 Reliability					
Not applicable					
4.0 Maintainability					
Not Applicable					
5.0 Producibility					
5.1 Low Cost - The cost of the tool should be less than $1500		6	4	24	*$1,000*
6.0 Dependencies					
6.1 API Support by HTTP Server The HTTP server should support remote method invocation by the visualization client running on the target platform.		10	0	0	
6.2 Bandwidth The visualization server part of the tool should run on a very powerful workstation to allow for continuous smooth animations while navigating through the model		7	0	0	The server should be at least a 250 MHz Processor with 4 GB Disk storage, 256 MB RAM.
			64	494	

220

4.0 Product Experience

The modeling programs were installed and exercised rigorously. For each program, we observed the model in both wireframe and rendered modes. We observed the refresh time and display quality (for rendered mode). The programs were found to be incapable of handling models at the required detail level in reasonable time. We next attempted to implement a hotspot for the model, using both the standard interface and the provided API. This testing sufficed to show that none of the technologies considered would be adequate for our needs. We also looked for the quality of the web interface for each of these products, and discovered that none of them supported any web interface.

In addition to the formal testing, several informal tests involving smaller models were employed. These showed that all of the programs ran acceptably on Pentium-class machines. However, the lack of an API for Director 6 Multimedia Studio made it unacceptable, even for smaller models. Also, the Soft F/X API was very small, requiring large amounts of code to be generated for even relatively trivial tasks.

5.0 Source Summary

The information on which the evaluation was based was drawn from a variety of sources. Material from the Web sites of all four vendors and other vendors such as Netscape provided much technical information about the packages under evaluation. The vendors' sales organizations and technical personnel were also contacted.

Company	Product Name / Contact
Macromedia	Director 6 Multimedia Studio http://www.macromedia.com/software/director/
Criterion Software	Renderware 2.1 http://www.csl.com/RenderWare/
Apple	QuickTime VR 2.0 and Virtual Tutor for QuickTime VR Bundle http://quicktimevr.apple.com/
Byte by Byte	Soft F/X http://bytebybyte.com/sfxhome.htm

A-8 Miniature Video Camera Trade Study

1.0 Summation

1.1 Purpose

The purpose of this trade study is to investigate small video cameras that could be mounted on a head worn display to transmit live video from a mechanic working on a plane to a remote expert. The original intent was to use these cameras in a help desk scenario or engineering collaboration scenario. A secondary purpose is to evaluate the capability of these same cameras to capture still images. In constructing the evaluation criteria, we assumed the cameras would need to be small and lightweight for use with a head worn display. We assumed that the bandwidth of the wireless transmission would be the limiting factor for video quality, and that the video quality of the cameras would need to be at least as good as allowed by the wireless transmission bottleneck.

1.2 Products

We evaluated the following products:

Company	Product Name
VLSI Vision Limited	VVL 5402 Lensed Module (Table A-8-2)
Marshall	V-1247 Color Camera (Table A-8-3)
Marshall	V1207 B&W camera (Table A-8-4
Marshal	V1207-PL B&W camera with pinhole lens (Table A-8-1)

Marshall decided not to produce the V1210-SCT miniature camera that was originally to be part of the trade if it became available, therefore only the above four cameras were part of the trade. They include one color camera, one CMOS camera - this is the first camera available of this new breakthrough technology (all the others are charge coupled device (CCD) cameras), a small back and white CCD camera, and a similar camera with a pinhole lens. Together these cover a broad spectrum of kinds of miniature cameras and technologies. While three of the four cameras are from the same manufacturer, we considered a much broader range of companies and cameras before downselecting to these. At the time of the downselect, Marshall offered the smallest black and white and color cameras available for CCD cameras. An unbiased camera expert at CMU reviewed our choices and assured us they represented a good evaluation set. Marshall can be contacted at (310) 390-6608 (phone) or (310) 391-8926 (fax). Their address is Marshall Electronics Inc. P.O. Box 2027, Culver City, CA 90231. VLSI Vision LTD. can be contacted at (408) 374-5323 (phone) or (408) 374-4722 (fax). Their address is 18805 Cox Avenue, Suite 260, Saratoga, CA 95070.

1.3 Environment

To test the cameras, we first constructed an adapter to provide power and output suitable for use with a TV monitor or computer. A schematic in included below. The adapter was constructed from the following materials:

1- Circuit Board and Box
1- 3 Pin Connector
1- 6 Pin Connector
1- 9v 300mA AC Wall Cube
2- RCA Jack Cables

The power source (VCC, Ground) connects to central pins. Wires run from those pins to camera jumper pins. This enables a compact and simple design for adaptation of various miniature camera models. Each camera is wired such that a simple "one way only" jumper dictates which camera plugs into a jumper, ensuring that polarity and audio\video pins connect correctly. The RCA Jacks are wired to central pins and connect to the appropriate camera jumper pins as well. These cables are applicable to common TV\VCR jacks as well as certain mobile computing devices. The power source connection could easily be modified to accommodate a DC power source (e.g. a 9V battery for mobile use).

We connected the video out jack from the cameras up to a MRT micro's VideoPort Professional framegrabber (www.mrtmicro.com), which digitizes the images and sends them to a laptop computer to display in 640x480 resolution. Note that the VGA resolution is independent of the resolution of the video cameras, which range from 220 to 380 TV lines (reported). We used an official test chart to compare the resolution and quality of the images, and evaluated them under conditions of high and low light.

1.4 Summary of Best Candidate

Of the cameras we evaluated, the Marshall V1207-PL B&W camera with pinhole lens is clearly the best choice for use with a head worn display. It has the highest quality image of the four cameras (see section II for a detailed analysis), and the smallest form factor. The pinhole lens gave it the clearest image. Combining these features with its moderate power consumption and overall robustness to different environmental conditions gave it the highest score of 921. It does have several shortcomings however. The pinhole mount makes it harder to attach other lenses if desired (unlike the Marshall V-1207 and the other cameras). In addition, it is a black and white camera - if color is required than a different camera should be used. Color CCD cameras are much heavier and bulkier in general and as a result are marginal for head worn use. Light, high resolution, color, CMOS cameras should soon be available from VVL and other companies. These represent the greatest hope for lightweight, color, and head worn cameras. In the meantime, of the reviewed cameras the 1207-PL is recommended.

1.5 Summary of the Other Products

The VV5402 lensed module is a new kind of camera based on CMOS technology. The image sensor is a CMOS array that is integrated with the rest of the electronics on a single chip. The ability to produce single chip cameras is a breakthrough, and in the long run will allow the production of cheaper high quality miniature video cameras in the $10-$20 range as opposed to the $100-$200 range for CCD cameras. Its overall score was 868. The camera has many pluses - its small, light, inexpensive, and draws little power. There is also the potential for a direct digital signal. The CMOS camera we examined actually converts its digital array to an analog NTSC signal. Our framegrabber then redigitizes the signal for display on a computer monitor. There is the possibility of connecting a digital output from a CMOS camera to a universal serial bus (USB) to avoid the digital (CMOS) to analog (NTSC) conversion followed by the analog (NTSC) to digital conversion. This could greatly improve the image quality of CMOS cameras. Although the VV5402 was the second highest rated camera, it still cannot be recommended for use yet. Its resolution and image quality are not quite high enough for practical use. The V1247 is a 1/5 CCD color camera and was the smallest color CCD camera we could find at the time of the downselect. Even though the V1247 is smaller and lighter than other color cameras, it is still substantially heavier and larger than the black and white cameras in the downselect. Unfortunately, the reduction to 1/5 CCD to reduce the size and power consumption of the camera also reduced the resolution and image quality. In addition, color cameras in general require greater minimum illumination than to black and white cameras (e.g. the 1247 was 15 Lux, while the 1207 and 1207-PL were both .4 Lux). This lack of adjustment under low light conditions is readily apparent in the jpegs presented in Supplement A-8-1 - the image is much darker than the other low light images. Its overall score was 856. The V1207 is similar to the 1207-PL except has a larger form factor and substantially worse image quality. Its overall score was 808.

1.6 Future Considerations

When we began this trade study, the initial prototypes to be developed in the ITI-ALC project included live video for collaboration and help desk scenarios. In the past month however, after visiting RAFB, we discovered that to collaborate with engineers, mechanics might only need high resolution, still, color images. This is reflected in the latest version of the collaboration scenario. While we may move to live video-using cameras mounted on head worn displays in future scenarios, it makes more sense now to use higher quality but bulkier hand held cameras for the initial collaboration scenario. Digital image capturing devices that connect directly to mobile computers may be more appropriate including color cameras by Pixera and VLSI Vision Limited (VVL).

As mentioned above, CMOS cameras appear to be the wave of the future for although the technology is not quite mature for miniature video cameras or our use. This should be reevaluated in the next six months.

2.0 Test Data

2.1 Resolution

Using the experimental apparatus described in section I, we collected still images from each of the cameras of a test chart used for assessing resolution. We took two images from each, one under high light conditions (with the lights on in the lab), and one with the lights off, but allowing a small amount of light in through the window blinds. These were meant to correspond roughly to lighting conditions in the hangar (1) near the exit on a sunny day and (2) inside a plane with ambient light. For reference, we include the high light and low light images for each camera in Supplement A-8-1. Note that these are scaled down to fit into this document, and so do not represent the raw image as viewed in the test (these are much smaller and so cannot be used to assess resolution). Still, they give a relative comparison of the different cameras and different conditions.

The test chart automatically normalizes for different cameras and lenses. The instructions say to move the camera until the full screen of the television or computer screen is taken up by chart. Then, to get a measure of the cameras resolution, find where the converging lines in the center and sides of the charge are not visually differentiable, and use the gauge next to the lines to determine the resolution. We used the chart in two ways - the first as described above to get an estimate of the resolution under different lighting conditions for each camera, and also to compare the overall visual quality of the cameras by evaluating the captured images in side by side comparisons as described in the next section. By viewing the images on a standard monitor, one person judged when the lines became undifferentiable for each camera under each condition (high light, low light). We decided this method yielded a high enough degree of accuracy for the purposes of the trade study (a second person double checked a few of the judgments with similar results). The observed resolution for each of the cameras was:

Camera	High Light Resolution	Low Light Resolution
V1207-PL	425	350
V1247	350	300
VV5402	325	310
V1207	275	240

Overall, the V1207-PL had the highest observed resolution under both lighting conditions. The V1247 and the VV5402 we both lower and had nearly the same observed resolution. Surprisingly, the V1207 had the lowest observed resolution, probably indicating that the pinhole lens creates a sharper image than the supplied lens with the V1207.

In all cases, the observed resolution for the high light condition was higher than the corresponding observed resolution in the low light condition. This means that regardless of the

camera we choose, we must understand the lighting conditions in which the camera will be used, and take that into account in the design.

Note that some of these observed resolutions differed from those reported by the companies. The V1247 and VV5402 did much better than their reported 220 TV lines, while the V1207-PL was consistent with its reported 380 TV lines. The observed resolutions for V1207 were lower than the value reported by Marshall. This variance is consistent with comments made by several independent vendors and experts we spoke with at CMU that for resolution, company reported values often differ considerably from those found in actual use.

2.2 Assessed Quality

In addition to resolution we wanted to get an overall sense of the still picture quality. We had five individuals rank by quality the images from the high light condition and the low light conditions. The following tables summarize the ranking of the images by all individuals:

Camera/Rank	1st	2nd	3rd	4th
V1207-PL	5	0	0	0
V1247	0	4	1	0
V1207	0	1	3	1
VV5402	0	0	1	4

Camera Rankings - High Light

Camera/Rank	1st	2nd	3rd	4th
V1207-PL	5	0	0	0
V1247	0	1	3	1
V1207	0	1	1	3
VV5402	0	3	1	1

Camera Rankings - Low Light

Each cell in the table gives the number of individuals who gave the specified camera the specified rank. By multiplying teach frequency by four minus the corresponding rank and summing across the ranks for each camera and across conditions, we get an overall preference score for each camera. The following table presents the overall ranked scores:

Camera	Overall Preference Score
V1207-PL	40
V1247	24
VV5402	18
V1207	18

Overall Quality Score

In both lighting conditions, the V1207-PL was ranked first by all participants, thus it was overwhelmingly preferred with a combined weighted score of 40. The V1247 was a distant second followed by the VV5402 and the V1207.

3.0 Assessment Tables

Table A-8-1 Video Camera Trade Study - Product: Marshall V1207-PL

Criteria	Rqmts	Weight	Score	Total	Comments
1.0 Performance					
Weight - Anything more than 2 ounces will be too heavy for head worn use. Lighter is better. For handheld use, this is less of an issue.	Derived 311005	9	8	72	.7 0z (20grams)
Shape/Size - The camera needs to be small enough so a technician will not accidentally hit into anything while wearing the camera. 1.25 inch cube is upper bound, but flatter is better	Derived 311005	9	9	81	1.5" X1.5" X .57" D
Mountability - Can the camera be mounted on a head worn display? Will the mounting be stable and rugged?	Derived 311005	9	7	63	mount will need to be constructed, but should not be hard
Power - 2W is rough upper bound depending on battery technology and if continuous or sporadic use.	Derived 311013	7	7	49	Less power than the V1247, same power V1207, more power than the VV5402.
1.1 Performance - assessed picture quality					
Resolution - High enough to display live video and snapshots to enable collaboration. Minimum resolution is probably 220 Horizontal TV lines. Higher (300-500 range) is desirable. Actual display resolution depends on bandwidth and software drivers.	Derived 311007	9	8	72	537Hx505V (380 TV lines) reported 425/350 (High/Low) observed
Quality (Still Print)	Derived 311007	9	9	81	Overall Quality: 40
Color or Black and White Video- There is a trade-off between size and picture quality. (Color cameras are larger) We still need to determine how useful color will be.	Derived 311005	5	5	25	b&w
Minimum Illumination - The camera needs to be able to operate in the range of lighting conditions that occur at the depot. 15 lux is upper bound for minimum.	Derived 311005	8	9	72	.4 Lux
Iris Control - Does camera have automatic (electronic) control? This helps in adjusting to different lighting conditions	Derived 311005	7	10	70	yes

Table A-8-1 Video Camera Trade Study - Product: Marshall V1207-PL (Continued)					
Lens Mount - Can a variety of lenses be attached? We need to be able to hook up lenses with a range of Field of View (35 to 90 degrees)	**Derived 311005**	9	8	72	Yes, wide, clear FOV (74 degrees horizontal, by 56 degrees vertical) and wide angle lens available
White Balance - (color cameras only) - Should be automatic - another factor in image quality	**Derived 311005**	7	NA		na
2.0 Reliability					
Ruggedness - Camera needs to be able to take impact and keep working if someone accidentally knocks it. i.e., needs strong housing and stable camera mount. (Vibration and shock values of 7G and 70G are excellent).	**Derived 311005**	8	7	56	More rugged than the V1247, at least as rugged as the other cameras (no hard data obtainable)
Operating Temperature - Camera should be able to work in wide range of temperatures (-10 C to 50 C)	**Derived 311017**	7	10	70	-10C - +55C
3.0 Maintainability					
Not Applicable					
4.0 Producibility					
Cost - most of these cameras range from $100-$250.		6	8	48	$155
5.0 Capability					
Output Signal - The camera should transmit output in an appropriate format for the wearable computer (NTSC, digital, etc.).	**Derived 311002**	9	10	90	NTSC
6.0 Dependencies					
Bandwidth - for use in collaboration, the bandwidth between computers will affect the quality of the video signal. E.g. for continuous video, if bandwidth is low, increasing the camera resolution will not improve the video signal	**Derived 311002**	8			
		Total:	115	921	

Table A-8-2 Video Camera: VVL 5402

Criteria	Rqmts	Weight	Score	Total	Comments
1.0 Performance					
Weight - Anything more than 2 ounces will be too heavy for head worn use. Lighter is better. For handheld use, this is less of an issue.	Derived 311005	9	10	90	12g
Shape/Size - The camera needs to be small enough so a technician will not accidentally hit into anything while wearing the camera. 1.25 inch cube is upper bound, but flatter is better	Derived 311005	9	8	72	22mm(h)x22mm(w)x24mm(d)
Mountability - Can the camera be mounted on a head worn display? Will the mounting be stable and rugged?	Derived 311005	9	7	63	Need to construct mount (yes)
Power - 2W is rough upper bound depending on battery technology and if continuous or sporadic use.	Derived 311013	7	10	70	~. 3W
1.1 Performance - assessed picture quality					
Resolution - High enough to display live video and snapshots to enable collaboration. Minimum resolution is probably 220 Horizontal TV lines. Higher (300-500 range) is desirable. Actual display resolution depends on bandwidth and software drivers.	Derived 311007	9	6	54	384x287 (265 TVL reported) 325/310 (High/low) observed
Quality (Still Print)	Derived 311007	9	4	32	Overall Quality: 18
Color or Black and White Video- There is a trade-off between size and picture quality. (Color cameras are larger) We still need to determine how useful color will be.	Derived 311005	5	5	25	B&W
Minimum Illumination - The camera needs to be able to operate in the range of lighting conditions that occur at the depot. 15 lux is upper bound for minimum.	Derived 311005	8	9	72	.5 lux
Iris Control - Does camera have automatic (electronic) control? This helps in adjusting to different lighting conditions	Derived 311005	7	10	70	AEC and AGC up to 99,000:1

Table A-8-2 Video Camera: VVL 5402

Lens Mount - Can a variety of lenses be attached? We need to be able to hook up lenses with a range of Field of View (35 to 90 degrees)	**Derived 311005**	9	8	72	Yes
White Balance - (color cameras only) - Should be automatic - another factor in image quality	**Derived 311005**	7	na		NA
2.0 Reliability					
Ruggedness - Camera needs to be able to take impact and keep working if someone accidentally knocks it. i.e., needs strong housing and stable camera mount. (Vibration and shock values of 7G and 70G are excellent).	**Derived 311005**	8	7	56	More rugged than the V1247, as rugged as the other cameras (No hard data obtainable)
Operating Temperature - Camera should be able to work in wide range of temperatures (-10 C to 50 C)	**Derived 311017**	7	6	42	0c - 40c
3.0 Maintainability					
Not Applicable					
4.0 Producibility					
Cost - most of these cameras range from $100-$250.		6	10	60	$100 now with potential to drop to $10 in bulk purchases
5.0 Capability					
Output Signal - The camera should transmit output in an appropriate format for the wearable computer (NTSC, digital, etc.).	**Derived 311002**	9	10	90	EIA (NTSC), possibility of digital
6.0 Dependencies					
Bandwidth - for use in collaboration, the bandwidth between computers will affect the quality of the video signal. E.g. for continuous video, if bandwidth is low, increasing the camera resolution will not improve the video signal	**Derived 311002**	8			
		Total:	110	868	

Table A-8-3 Video Camera Trade Study - Product: Marshall V1247

Criteria	Rqmts	Weight	Score	Total	Comments
1.0 Performance					
Weight - Anything more than 2 ounces will be too heavy for head worn use. Lighter is better. For handheld use, this is less of an issue.	**Derived 311005**	9	5	45	1.4 0z (40 grams)
Shape/Size - The camera needs to be small enough so a technician will not accidentally hit into anything while wearing the camera. 1.25 inch cube is upper bound, but flatter is better	**Derived 311005**	9	5	45	1.5"Lx1.5"Wx1.75"H
Mountability - Can the camera be mounted on a head worn display? Will the mounting be stable and rugged?	**Derived 311005**	9	7	63	mount will need to be constructed, but should not be hard
Power - 2W is rough upper bound depending on battery technology and if continuous or sporadic use.	**Derived 311013**	7	6	42	2.16W
1.1 Performance - assessed picture quality					
Resolution - High enough to display live video and snapshots to enable collaboration. Minimum resolution is probably 220 Horizontal TV lines. Higher (300-500 range) is desirable. Actual display resolution depends on bandwidth and software drivers.	**Derived 311007**	9	7	63	(220 TV lines) reported 350/300 (High/Low) observed
Quality (Still Print)	**Derived 311007**	9	6	54	overall quality: 24
Color or Black and White Video- There is a trade-off between size and picture quality. (Color cameras are larger) We still need to determine how useful color will be.	**Derived 311005**	5	10	50	color
Minimum Illumination - The camera needs to be able to operate in the range of lighting conditions that occur at the depot. 15 lux is upper bound for minimum.	**Derived 311005**	8	5	40	15 Lux
Iris Control - Does camera have automatic (electronic) control? This helps in adjusting to different lighting conditions	**Derived 311005**	7	10	70	yes

Table A-8-3 Video Camera Trade Study - Product: Marshall V1247 (Continued)

Lens Mount - Can a variety of lenses be attached? We need to be able to hook up lenses with a range of Field of View (35 to 90 degrees)	**Derived 311005**	9	8	72	yes
White Balance - (color cameras only) - Should be automatic - another factor in image quality	**Derived 311005**	7	10	70	yes
2.0 Reliability					
Ruggedness - Camera needs to be able to take impact and keep working if someone accidentally knocks it. I.e. needs strong housing and stable camera mount. (Vibration and shock values of 7G and 70G are excellent).	**Derived 311005**	8	5	40	Least rugged of the four cameras due to its two connected boards (no hard data obtainable)
Operating Temperature - Camera should be able to work in wide range of temperatures (-10 C to 50 C)	**Derived 311017**	7	10	70	-10C - +55C -20 - +70C in storage
3.0 Maintainability					
Not Applicable					
4.0 Producibility					
Cost - most of these cameras range from $100-$250.		6	7	42	$245
5.0 Capability					
Output Signal - The camera should transmit output in an appropriate format for the wearable computer (NTSC, digital, etc.).	**Derived 311002**	9	10	90	NTSC
6.0 Dependencies					
Bandwidth - for use in collaboration, the bandwidth between computers will affect the quality of the video signal. E.g. for continuous video, if bandwidth is low, increasing the camera resolution will not improve the video signal	**Derived 311002**	8			
		Total:	111	856	

Table A-8-4 Video Camera Trade Study - Product: Marshall V1207

Criteria	Rqmts	Weight	Score	Total	Comments
1.0 Performance					
Weight - Anything more than 2 ounces will be too heavy for head worn use. Lighter is better. For handheld use, this is less of an issue.	**Derived 311005**	9	8	72	.7 Oz (20grams)
Shape/Size - The camera needs to be small enough so a technician will not accidentally hit into anything while wearing the camera. 1.25 inch cube is upper bound, but flatter is better	**Derived 311005**	9	7	63	1.25" X1.25" X .1.25" D
Mountability - Can the camera be mounted on a head worn display? Will the mounting be stable and rugged?	**Derived 311005**	9	7	63	mount will need to be constructed, but should not be hard
Power - 2W is rough upper bound depending on battery technology and if continuous or sporadic use.	**Derived 311013**	7	7	49	Lower than the V1247, higher than the VV5402
1.1 Performance - assessed picture quality					
Resolution - High enough to display live video and snapshots to enable collaboration. Minimum resolution is probably 220 Horizontal TV lines. Higher (300-500 range) is desirable. Actual display resolution depends on bandwidth and software drivers.	**Derived 311007**	9	4	32	537Hx505V (380 TV lines) reported 275/240 (hi/low) observed
Quality (still print)	**Derived 311007**	9	4	32	Overall Quality: 18
Color or Black and White Video - There is a trade-off between size and picture quality. (Color cameras are larger) We still need to determine how useful color will be.	**Derived 311005**	5	5	25	b&w
Minimum Illumination - The camera needs to be able to operate in the range of lighting conditions that occur at the depot. 15 lux is upper bound for minimum.	**Derived 311005**	8	9	72	.4 Lux
Iris Control - Does camera have automatic (electronic) control? This helps in adjusting to different lighting conditions	**Derived 311005**	7	10	70	yes

Table A-8-4 Video Camera Trade Study - Product: Marshall V1207

Lens Mount - Can a variety of lenses be attached? We need to be able to hook up lenses with a range of Field of View (35 to 90 degrees)	**Derived 311005**	9	8	72	yes
White Balance - (color cameras only) - Should be automatic - another factor in image quality	**Derived 311005**	7	na		na
2.0 Reliability					
Ruggedness - Camera needs to be able to take impact and keep working if someone accidentally knocks it. i.e., needs strong housing and stable camera mount. (Vibration and shock values of 7G and 70G are excellent).	**Derived 311005**	8	7	56	More rugged than the V1247, probably as rugged as the other cameras (no hard data obtainable)
Operating Temperature - Camera should be able to work in wide range of temperatures (-10 C to 50 C)	**Derived 311017**	7	10	70	-10C - +55C
3.0 Maintainability					
Not Applicable					
4.0 Producibility					
Cost - most of these cameras range from $100-$250.		6	7	42	$155
5.0 Capability					
Output Signal - The camera should transmit output in an appropriate format for the wearable computer (NTSC, digital, etc.).	**Derived 311002**	9	10	90	NTSC
6.0 Dependencies					
Bandwidth - for use in collaboration, the bandwidth between computers will affect the quality of the video signal. E.g. for continuous video, if bandwidth is low, increasing the camera resolution will not improve the video signal	**Derived 311002**	8			
		Total:	103	808	

4.0 Experience

In addition to performing the tests described in section two, we informally evaluated the cameras using a direct hook up to a TV monitor and viewing people, objects, and written text. By far, the V1207-PL had the clearest image, with the V1247 and V1207 close behind. The color in the V1247 gave a greater sense of reality to the video and allowed a greater distinction between objects, when the room had sufficient light for the color contrasts to come through. The video from VV5402 was the worst, regardless of the lenses we tried with it. The contrast in the VV5402 seemed lower than that of the other cameras, resulting in a smoother but more washed out video image.

5.0 Product Data Sheets

Product data sheets can be obtained from the following web sites:

Marshall Cameras: http://www.mars-cam.com/
VLSI Vision Ltd.: http://www.vvl.co.uk/

Miniature Video Camera Trade Study

Supplement A-8-1 Stills of Resolution Chart
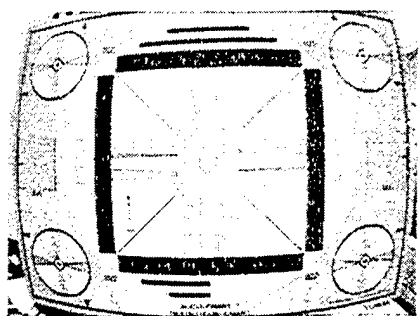
V1207 High light
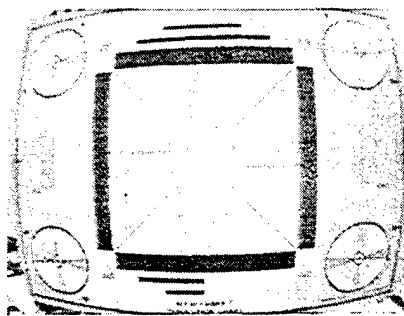
V1207 Low light
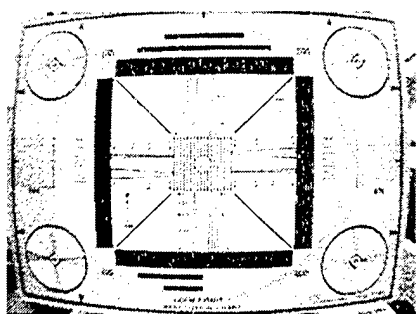
V1207-PL High light
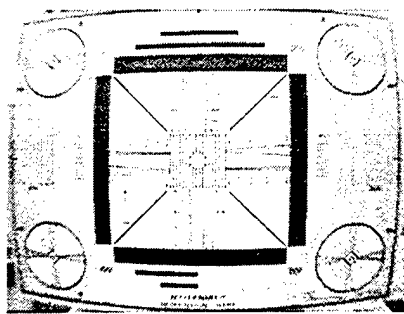
V1207-PL Low light
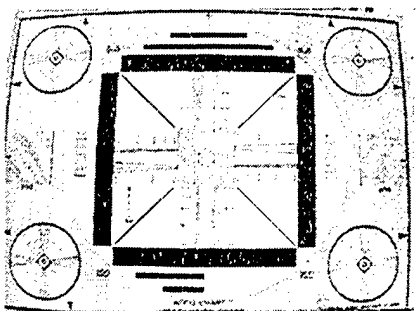
V1247 High light
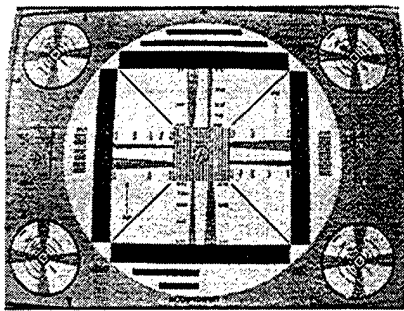
V1247 Low light
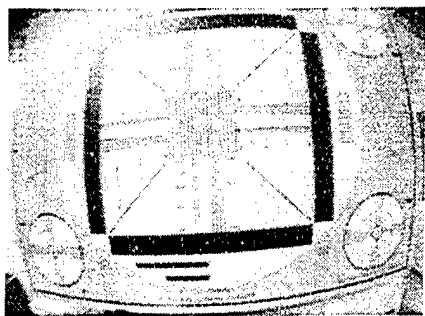
VV5402 High Light
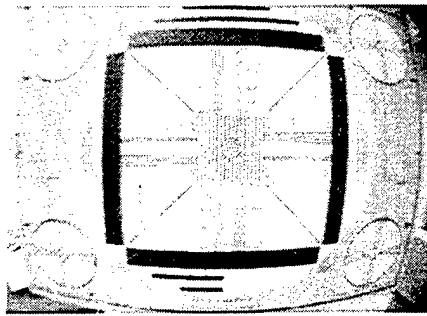
VV5402 Low light

APPENDIX B

USABILITY EVENTS QUESTIONNAIRES

Appendix B: Usability Events Questionnaires

ITI-ALC Phase II
FBE #2
Post Questionnaire

Name _____

1. Did you use the mobile prototype?
      ____Yes   ____No

If "No", why not?

_____

_____

Please go to question 8.

If yes, please answer questions 2 through 10.

Please circle your answer:

	Very Easy				*Very Difficult*
2. Seeing the text in the application was	1	2	3	4	5
3. Seeing the graphic representation of the aircraft was	1	2	3	4	5
4. Finding the information I needed for the E&I inspection or Form 202 task was	1	2	3	4	5

5. What do you like best about using the mobile system to access the F-15 E &I or Form 202 information?

_____

_____

_____

6. What do you like least about using the mobile to access the F-15 E &I or Form 202 information?

_____

_____

7. For the F-15 E& I inspection or the Form 202 task, was there any information you needed that was unavailable to you? _____yes _____no
If "yes", please describe briefly_____

_____

8. What would you change about the mobile system if you could? (for example, would you want: bigger screen, faster response time, fewer handwriting recognition errors, easier ways to change responses)

_____

_____

_____

_____

9. Please describe briefly how you felt about using the computer to record information instead of using paper:

_____

_____

10. Is there anything else you would like us to know about your experience with mobile computing today?

_____

_____

_____

_____

Thank you for your participation in this evaluation session.

APPENDIX C

FIELD BASED EVALUATION QUESTIONS

Appendix C: Field Based Evaluation Questions

The following questions are about the ITI-ALC system you just used. The questions are grouped in three sections. The first section asks general questions about this kind of maintenance aid. In other words, not necessarily this system, but one like it. The second section asks questions about how the ITI-ALC system effects your ability to perform your job. The third section asks questions about how easy the hardware and software are to use.

Please answer all questions that you can. Indicate your answer by circling the choice you select. If you cannot answer a question, leave it blank.

ITI-ALC CONCEPT

1. Would an ITI-ALC system increase your use of TO data?

   [A1] Not at all   1   2   3   4   5   Definitely

2. Would an ITI-ALC system increase access to <u>most</u> types of information needed for your job?

   [A2]Yes   No

   If no, why not

   _____

   _____

3. An ITI-ALC system would make estimates of task time to complete [A3]
   More accurate   1   2   3   4   5   Less accurate

4. If an ITI-ALC system were available, would you draw with it?[A4]
   Yes   No   Maybe

5. Would an ITI-ALC system be easy for a novice maintenance technician to use? [A5]
   Yes   No   Maybe

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6. Performing tasks outside your specialty with an ITI-ALC system would be[A6]

   Possible   1   2   3   4   5   Impossible

7. If you had an ITI-ALC system, would you use it for your primary job? [A7]

   Yes   No   Depends

   If no, why not

   _____

   _____

8. If an ITI-ALC system were available to you, you would use it[A8]

   Never 1   2   3   4   5   Frequently

9. Are there maintenance areas where an ITI-ALC system would be useful?

   Yes   No

   If yes, which ones? [A9]

   _____

   _____

   _____

10. Are there maintenance areas where an ITI-ALC system would NOT be useful?

    Yes   No

    If yes, which ones? [A10]

    _____

    _____

    _____

ITI-ALC's EFFECT ON YOUR JOB PERFORMANCE

1. Obtaining information using the ITI-ALC system as compared to current TOs was (Answer both sets of responses)

[A11]   Faster   Slower   Same

Easier   Harder   Same

2. Obtaining forms using the ITI-ALC system as compared to the current process for obtaining forms was (Answer both sets of responses)

[A12]   Faster   Slower   Same

Easier   Harder   Same

3. Ability to access other types of information (e.g., parts information) using the ITI-ALC system as compared to the current method was (Answer both sets of responses)

Faster   Slower   Same

Easier   Harder   Same

4. Compared to the current process, ordering parts with ITI-ALC would be was (Answer both sets of responses)

[A13]   Faster   Slower   About the same

Easier   Harder   Same

5. Time required to enter information into the ITI-ALC system as opposed to the current method was
   [A14]
   Longer   Shorter   Same

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6. To accomplish most tasks, the digital camera provided[A15]

   Inadequate detail   1   2   3   4   5   Sufficient detail

7. If you had digital photos of damaged areas, the number of trips to the aircraft to view the damage would [A16]

   Remain the same   Decrease

8. Use of the I-button would make the signature approval time[A17]

   Faster   1   2   3   4   5   Slower

9. In comparison with the current signature security process, the I-button would make signature approval security [A18]

   Less secure   1   2   3   4   5   More secure

10. Compared to the current system, time required to send information using the ITI-ALC system was [A19]

    Longer   Shorter   Same

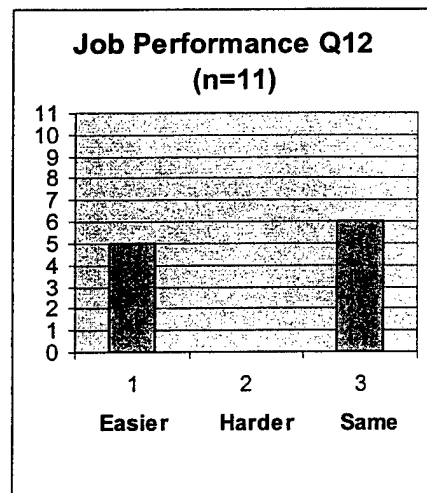11. While carrying/wearing the system, it interfered with the maintenance task [A20]

    Infrequently   1   2   3   4   5   Frequently

12. As compared with paper, information presented on the ITI-ALC system was [A21]

    Easier to read   Harder to read   About the same

ITI-ALC HARDWARE AND SOFTWARE USE

1. Carrying/wearing the ITI-ALC system while performing your task was [A22]

   Convenient   1   2   3   4   5   Inconvenient

2. Was the system comfortable to wear? [A23]

   Yes   No

3. Did the straps fasten the ITI-ALC system securely to your body? [A24]

   Yes   No

4. While using the computer to perform your task, the use of the pen was:

Easy   1   2   3   4   5   Difficult

5. Was it obvious when the computer was busy working? [A25]

Yes   No

If no, when

_____

_____

6. Information presented on the ITI-ALC system was [A26]

Easy to read   1   2   3   4   5   Difficult to read

7. Information you entered into the ITI-ALC system was[A27]

Easy to read   1   2   3   4   5   Difficult to read

8. Information presented on the ITI-ALC system was [A28]

Adequate   1   2   3   4   5   Inadequate

9. Entering text using the on-screen keyboard was [A29]

Easy   1   2   3   4   5   Difficult

10. The meaning of the "stamp" icon was

Not obvious   Obvious

If it was not obvious, what would you suggest?

_____

11. The meaning of the "envelope" icon

Not obvious   Obvious

If it was not obvious, what would you suggest?

_____

12. The navigation bar on the right side of the computer was

Easy to understand   1   2   3   4   5   Difficult to understand

13. Entering sketches on the ITI-ALC system was[A30]
    Easy   1   2   3   4   5   Difficult

14. Using the camera to photograph damaged area was [A31]
    Easy   1   2   3   4   5   Difficult

15. Reviewing photos you had taken was[A32]
    Easy   1   2   3   4   5   Difficult

16. Did you notice when photos were available for you to review[A33]
    Yes   No

17. Saving photos on the computer was[A34]
    Easy   1   2   3   4   5   Difficult

18. Viewing photos was [A35]
    Easy   1   2   3   4   5   Difficult

19. Recording voice notes was[A36]
    Easy   1   2   3   4   5   Difficult

20. Playing back voice notes was[A37]

Easy 1 2 3 4 5 Difficult

21. Reviewing voice notes you had recorded was [A38]

Easy 1 2 3 4 5 Difficult

22. Did you notice when voice notes were available for you to review [A39]

Yes No

23. Transmitting information for other people to read or approve was [A40]

Easy 1 2 3 4 5 Difficult

24. Did you know when the computer was sending data? [A41]

Yes No

25. The ITI-ALC system was [A42]

Not useful 1 2 3 4 5 Very Useful

26. What did you like most about the ITI-ALC system?[A43]

_____

_____

_____

27. What did you like least about the ITI-ALC system?[A44]

_____

_____

Did you use an ITI-ALC system in a previous study?

Yes   No   Don't remember

28. If yes, which one (screen presentations primarily) did you prefer? [A45]

Previous ITI-ALC system   This ITI-ALC system

APPENDIX D

COMPLETED SHAKEDOWN EVENT QUESTIONNAIRES

Appendix D: Completed Shakedown Event Questionnaires

1.0 AFRL Participant 1

1. Did you use the mobile prototype?   __**X**__ Yes   ____ No

If "No", why not?

_____

Please go to question 8.

If yes, please answer questions 2 through 8.

Please circle your answer:

	Very Easy				*Very Difficult*
2. Seeing the text in the application was	1 **X**	2	3	4	5
3. Seeing the graphic representation of the aircraft was	1 **X**	2	3	4	5
4. Finding the information I needed for the inspection or Form 202 task was	1 **X**	2	3	4	5

5. What do you like best about using the mobile system to access the F-15 E &I or Form 202 information?
very simple to work with and can be used in any environment, paperwork tends to get lost, blown away or rained on

6. What do you like least about using the mobile to access the F-15 E &I or Form 202 information?
didn't have anything I disliked, but just might be easier to find a blank defect form button on the main screen

7. For the F-15 E&I inspection or the Form 202 task, was there any information you needed that was unavailable to you? _X_ yes ___ no
If yes, please describe briefly
how to determine exactly what T.O. to use when creating the 202 from the blank form

8. What would you change about the mobile system if you could? (for example, would you want: bigger screen, faster response time, fewer handwriting recognition errors, easier ways to change responses) probably, my biggest difficulty was using the pen and identifying characters from the pen, seem to take many tries to accomplish. I think also a smaller unit to fit in one hand for cockpit areas and inspections in tighter areas

9. Please describe briefly how you felt about using the computer to record information instead of using paper:
I thought the computer was very helpful, and much better than the paper process we use now. It could be set up even easier by putting steps in a logical sequence (i.e. step 1, step 2, etc)

10. Is there anything else you would like us to know about your experience with mobile computer today?
I enjoyed taking part of this testing of the mobile system. I found it very simple and very useful and hope to use this system in the future

2.0 AFRL Participant 2

1. Did you use the mobile prototype? __X__Yes _____ No

If "No", why not?

_____

Please go to question 8.

If yes, please answer questions 2 through 8.

Please circle your answer:

	Very Easy				Very Difficult
2. Seeing the text in the application was	1 X	2	3	4	5
3. Seeing the graphic representation of the aircraft was	1 X(3a)	2	3	4	5 X(3b)
4. Finding the information I needed for the inspection or Form 202 task was	1 X	2	3	4	5

5. What do you like best about using the mobile system to access the F-15 E &I or Form 202 information?

It was simple to use. It's a quick way to move information to decrease time

6. What do you like least about using the mobile to access the F-15 E &I or Form 202 information?
The pen was easy to use...but at times it was sensitive and did not respond. (multiple use for a single action)

7. For the F-15 E&I inspection or the Form 202 task, was there any information you needed that was unavailable to you? _X_ yes ___ no
If yes, please describe briefly
Question "3B" The inspection called for information out of IF.15E-3-8, which the 3-8 didn't have.

8. What would you change about the mobile system if you could? (for example, would you want: bigger screen, faster response time, fewer handwriting recognition errors, easier ways to change responses)
Like I mentioned reduce the sensitivity of the pen, everyone wants faster response time from computers! Using the pen and touching keyboard buttons can be tedious after a while

9. Please describe briefly how you felt about using the computer to record information instead of using paper:
The system seems to work great, I have some computer background, so it was easy   to pick up. My only concern with all computer programs is "If they crash no way around it." Paper does fail

10. Is there anything else you would like us to know about your experience with mobile computer today?
It was fun, I enjoyed it, a good system

3.0 AFRL Participant 3

1. Did you use the mobile prototype? __X__ Yes _____ No

If "No", why not?

_____

Please go to question 8.

If yes, please answer questions 2 through 8.

Please circle your answer:

	Very Easy				Very Difficult
2. Seeing the text in the application was	1 **X**	2	3	4	5
3. Seeing the graphic representation of the aircraft was	1	2 **X**	3	4	5
4. Finding the information I needed for the inspection or Form 202 task was	1	2 **X**	3	4	5

5. What do you like best about using the mobile system to access the F-15 E &I or Form 202 information?
I liked the easy access to the task listing and ability to pull up common defects directly from the task listing, using the icon

6. What do you like least about using the mobile to access the F-15 E &I or Form 202 information?
I didn't like being sent back to the top of the task list once defects were noted. I would have preferred to be sent back to the area on the task listing that I left

7. For the F-15 E&I inspection or the Form 202 task, was there any information you needed that was unavailable to you? ___ yes _X_ no

If yes, please describe briefly ___N/A_____

8. What would you change about the mobile system if you could? (for example, would you want: bigger screen, faster response time, fewer handwriting recognition errors, easier ways to change responses)
Faster response times, better ability to click (had problems with the pen system). Also would find a way to let technician know if they were about to exit without submitting defects during that session

9. Please describe briefly how you felt about using the computer to record information instead of using paper:
Loved it.

10. Is there anything else you would like us to know about your experience with mobile computer today?
I found it very useful as a guide of how to perform E&I inspection. For non-experienced inspectors, this would be a great tool

4.0 AFRL Participant 4

1. Did you use the mobile prototype? __X__ Yes _____ No

If "No", why not?
_____

Please go to question 8.

If yes, please answer questions 2 through 8.
Please circle your answer:

	Very Easy				*Very Difficult*
2. Seeing the text in the application was	1	2 **X**	3	4	5
3. Seeing the graphic representation of the aircraft was	1	2 **X**	3	4	5
4. Finding the information I needed for the inspection or Form 202 task was	1 **X**	2	3	4	5

5. What do you like best about using the mobile system to access the F-15 E &I or Form 202 information?
<u>System uses the same software currently used throughout industry</u>

6. What do you like least about using the mobile to access the F-15 E &I or Form 202 information?
<u>It should be versatile, meaning touch with fingers or the pen</u>

7. For the F-15 E&I inspection or the Form 202 task, was there any information you needed that was unavailable to you? ___ yes _X_ no
If yes, please describe briefly ___N/A_____

8. What would you change about the mobile system if you could? (for example, would you want: bigger screen, faster response time, fewer handwriting recognition errors, easier ways to change responses)
<u>Bigger screen would help, but if the fields were a little bigger or if we had the option to increase or decrease size would help. Need feedback to mechanic before he sends the 202A that a voice and picture are really attached. The bungee material used on the pen tends to wrap around the device.</u>

9. Please describe briefly how you felt about using the computer to record information instead of using paper:

Much easier and handier than utilizing 3 or 4 items that thins unit replaces

10. Is there anything else you would like us to know about your experience with mobile computer today?

APPENDIX E

QUESTIONNAIRE, PARTICIPANT COMMENTS AND
TEST ADMINISTRATOR OBSERVATIONS

Appendix E:

Questionnaire, Participant Comments and Test Administrator Observations

ITI-ALC Concept

1. Would an ITI-ALC system increase your use of TO data?
   <u>Inspectors</u>
   Not applicable
   Didn't use TOs
   <u>Mechanics</u>
   If TO is checked out then you have to hunt for it.

Concept Q1   (n=8)
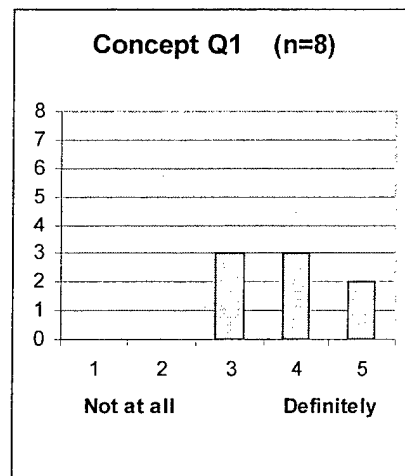
2. Would an ITI-ALC system increase access to <u>most</u> types of information needed for your job?
   <u>Inspectors</u>
   Don't know
   <u>Mechanics</u>
   Availability
   But the system was very very slow searching for information from the TOs
   [Some participants had difficulty calling up the ITI-ALC tech data. Some subsections were hundreds of pages of PDF files, which took an inordinate time to load.]
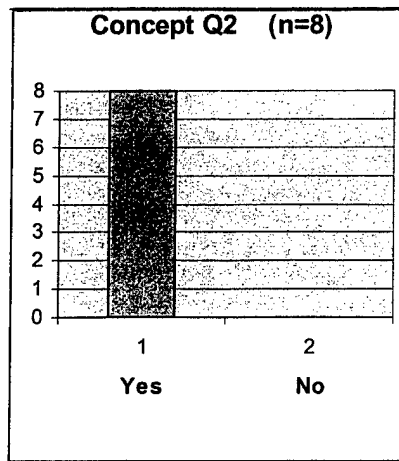
Concept Q2   (n=8)

8
7
6
5
4
3
2
1
0

1   2
Yes   No

3. An ITI-ALC system would make estimates of task time to complete

Concept Q3   (n=9)

9
8
7
6
5
4
3
2
1
0

1   2   3   4   5
More accurate   Less accurate
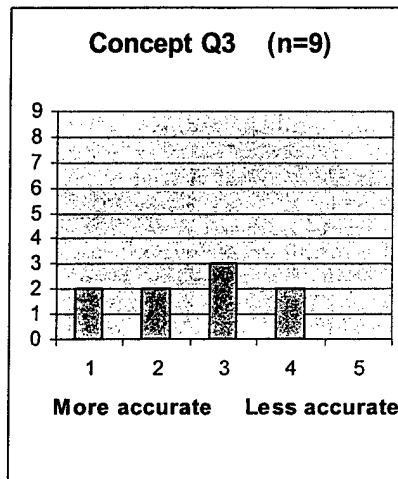
4. If an ITI-ALC system were available, would you draw with it?
    Mechanics
    Would use the picture capability more than the drawing capability
    Engineers
    As a supervisor maybe

Concept Q3   (n=9)

9
8
7
6
5
4
3
2
1
0

1   2   3   4   5
More accurate   Less accurate
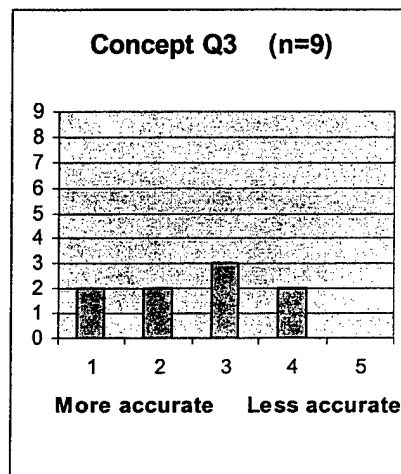
5. Would an ITI-ALC system be easy for a novice maintenance technician to use?
   Inspectors
   As easy as it is for the inspector
   With practice
   Mechanics
   Had never seen before yesterday and no computer experience
   If familiar with computers

Concept Q5   (n=8)

	1	2	3
	Yes	No	Maybe
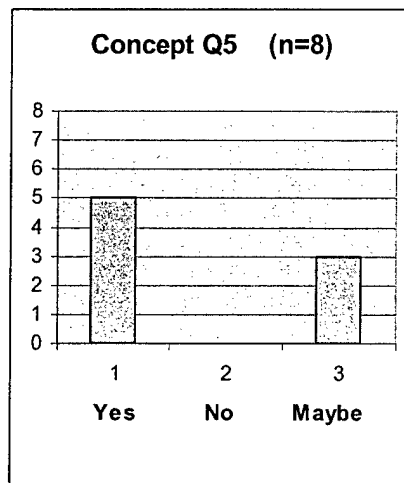
6. Performing tasks outside your specialty with an ITI-ALC system would be
   Inspectors
   I-button makes it impossible
   Mechanics
   If dual skill
   Don't know

Concept Q6   (n=9)

9				
8				
7				
6				
5				
4				
3	▓		▓	
2	▓	▓	▓	
1	▓	▓	▓	▓
0				

1	2	3	4	5
Possible			**Impossible**	
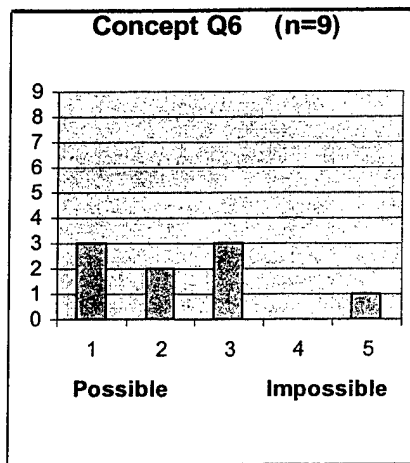
7. If you had an ITI-ALC system, would you use it for your primary job?
   Inspectors
   If more training
   Mechanics
   Engineering assistance, part numbers
   For writing 202s
   If I needed to pull up information to do job

Concept Q7   (n=11)

1	2	3
Yes	**No**	**Depends**
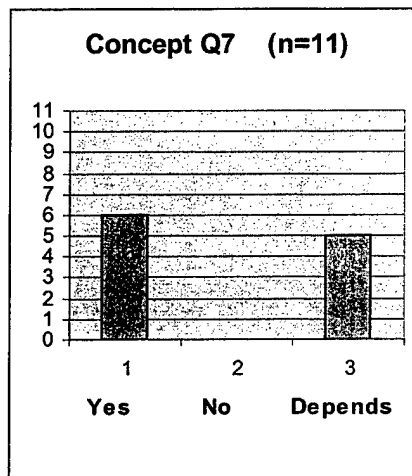
8. If an ITI-ALC system were available to you, you would use it
   Mechanics
   If TOs were changes. Definitely for 202s
   202s and part numbers
   Currently we use blueprints, parts kits, and have all paperwork needed

Concept Q8   (n=11)
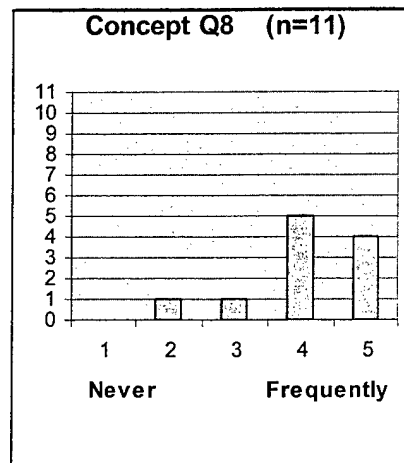
9. Are there maintenance areas where an ITI-ALC system would be useful? If yes, which ones?
   Inspectors
   Other weapon systems.
   All depot maintenance on aircraft, parts being ordered, E&I, information to technicians, etc.
   Cockpit. Tail to horizontal stabilizer
   Mechanics
   202s, TOs, Ordering parts
   Areas where a repair in the TO can't be found
   All depot level maintenance tasks, because of being able to access TOs. Have to access TOs first.
   Part numbers, repairs, general information—TOs
   AC maintenance mechanics could use in place of written TO.
   Engineers
   All
   Documentation, tracking and trending of assistance requests

Concept Q9   (n=10)
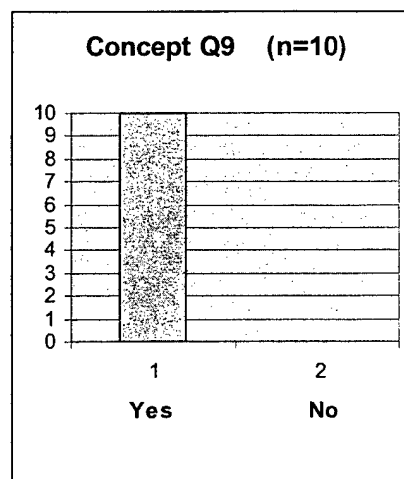
10. Are there maintenance areas where an ITI-ALC system would NOT be useful? If yes, which ones?
    Inspectors
    Fuel tank
    Mechanics

Tight areas
In place of large blueprints such as the ones we use when performing TOs.

Concept Q10   (n=11)
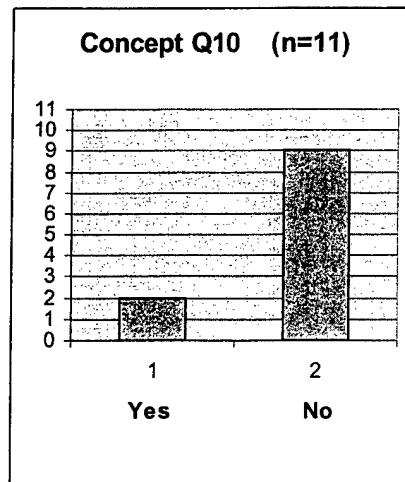
ITI-ALC's Perceived Effect on Job Performance

1. Obtaining information using the ITI-ALC system as compared to current TOs was
   Inspectors
   Familiar
   Mechanics
   Easier depends on how easy computer is to obtain
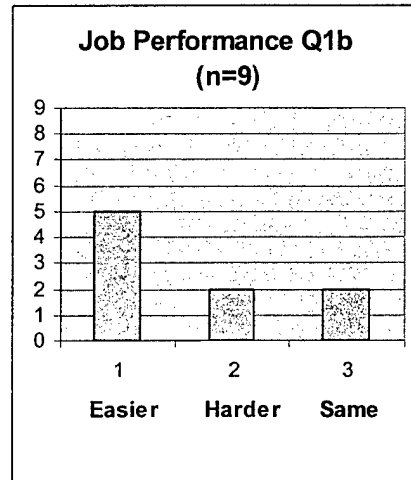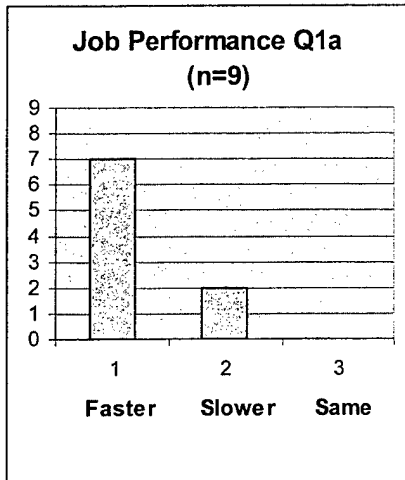
Job Performance Q1a (n=9)

Response	Count
1 Faster	7
2 Slower	2
3 Same	0

Job Performance Q1b (n=9)

Response	Count
1 Easier	5
2 Harder	2
3 Same	2

2. Obtaining forms using the ITI-ALC system as compared to the current process for obtaining forms was
   Mechanics
   Prefilled information is helpful
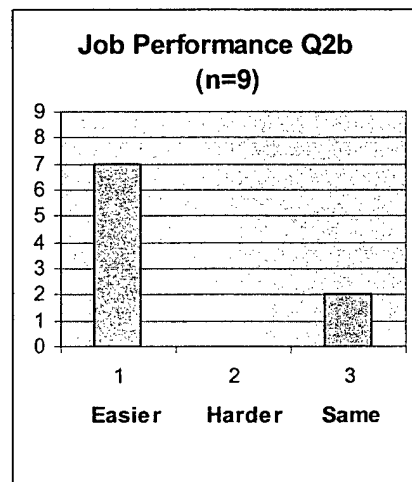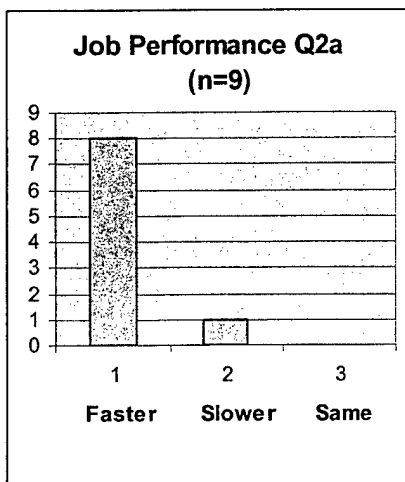
Job Performance Q2a (n=9)

Response	Count
1 Faster	8
2 Slower	1
3 Same	0

Job Performance Q2b (n=9)

Response	Count
1 Easier	7
2 Harder	0
3 Same	2

3. Ability to access other types of information (e.g., parts information) using the ITI-ALC system as compared to the current method was
Inspectors
Didn't access TOs or parts

Job Performance Q3a (n=9)

1 Faster	6
2 Slower	1
3 Same	2

Job Performance Q3b (n=9)

1 Easier	5
2 Harder	2
3 Same	2
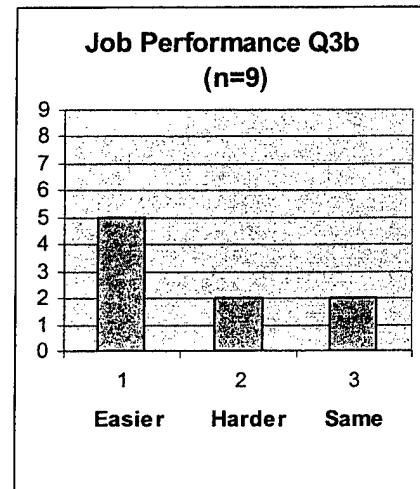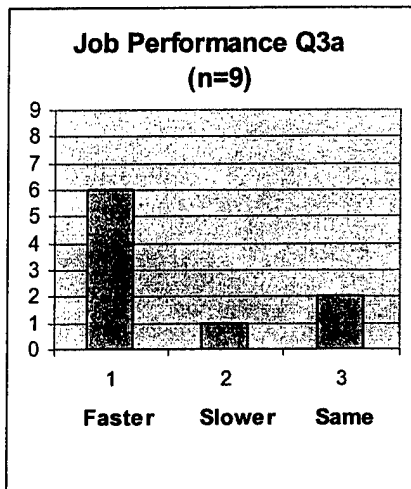
4. Compared to the current process, ordering parts with ITI-ALC would be/was
Inspectors
Hard to say
Familiar
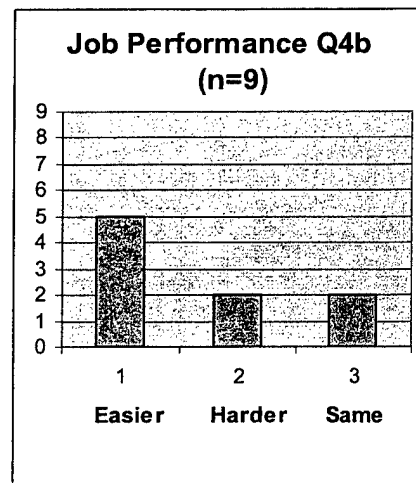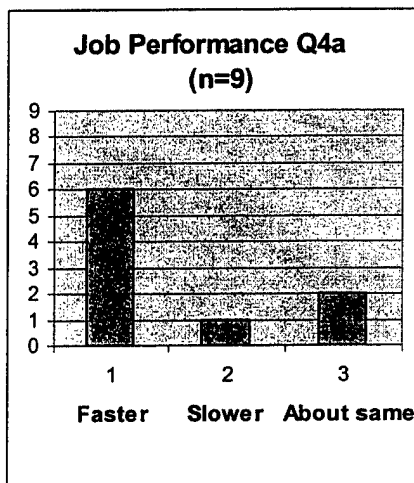
Job Performance Q4a (n=9)

1 Faster	6
2 Slower	1
3 About same	2

Job Performance Q4b (n=9)

1 Easier	5
2 Harder	2
3 Same	2

5. Time required to enter information into the ITI-ALC system as opposed to the current method was

Mechanics
Extra information

**Job Performance Q5
(n=11)**

	Longer	Shorter	Same
	1	2	3

Bar chart with y-axis from 0 to 11: category 1 (Longer) = 1, category 2 (Shorter) = 8, category 3 (Same) = 2.
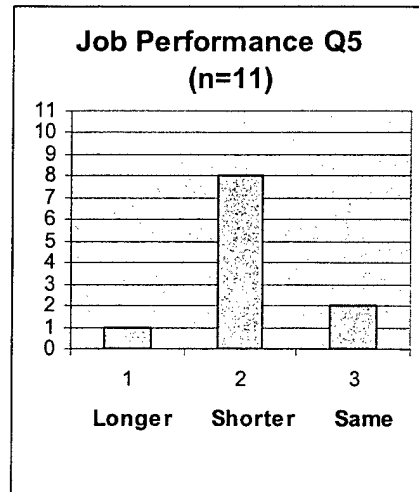
6. To accomplish most tasks, the digital camera provided
   Mechanics
   Jumps a lot better than last time
   Getting image where you wanted it. Keeping at same distance while focusing
   Will take picture of where it is. Use a magnifying glass normally. Zoom in may not give all the detail you need
   Needs to be autofocus
   Engineers
   Camera may not be sufficient for all cases. Pictures were out of focus. The pictures need to be tied to the aircraft location.
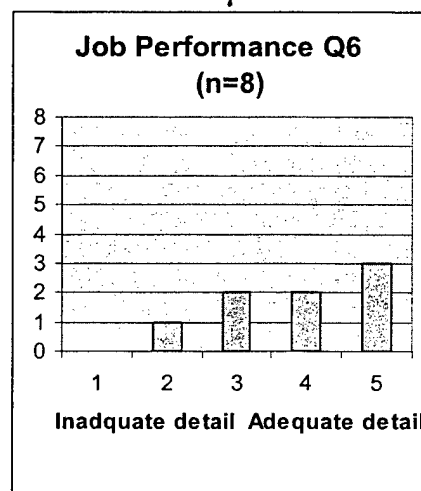
**Job Performance Q6
(n=8)**

Bar chart with y-axis from 0 to 8, x-axis categories 1 to 5, labeled "Inadquate detail" at left and "Adequate detail" at right: category 1 = 0, category 2 = 1, category 3 = 2, category 4 = 2, category 5 = 3.

7. If you had digital photos of damaged areas, the number of trips to the aircraft to view the damage would

Engineers

If the engineer could request further clarification it would decrease the number of trips even further

[Engineers wanted to be able to request further clarification from the mechanic, allow the mechanic to update/modify the 202A and resubmit]

Job Performance Q7
(n=2)
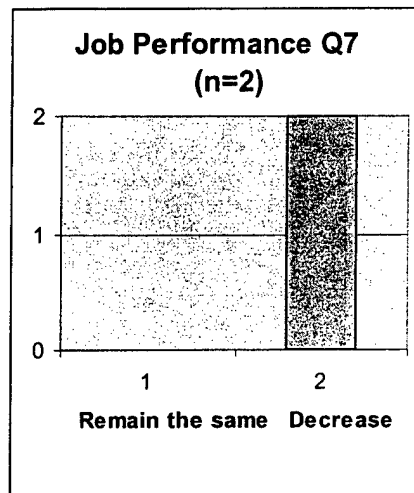
8. Use of the I-button would make the signature approval time

Inspectors

Don't know what to say about it
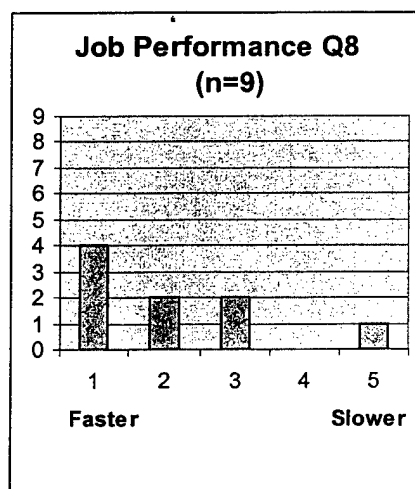
Job Performance Q8
(n=9)

9. In comparison with the current signature security process, the I-button would make signature approval security
Mechanics
Could be lost like anything
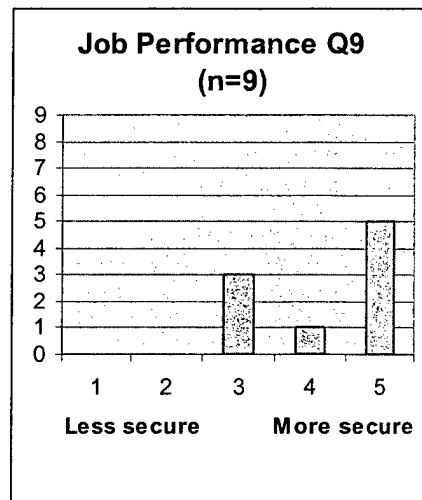
Job Performance Q9 (n=9)

	1	2	3	4	5
Less secure			3	1	5
More secure					

10. Compared to the current system, time required to send information using the ITI-ALC system was
Mechanics
Could be several days

Job Performance Q10 (n=11)

	1	2	3
	Longer	Shorter	Same
	1	10	
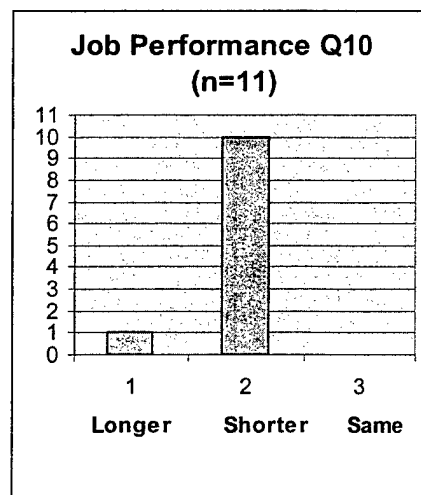
11. While carrying/wearing the system, it interfered with the maintenance task
Inspectors

Very little
Mechanics
Filling out 202. Would take the computer off for maintenance
If forms, then it did not interfere
I don't think it would affect it much
Depends on where on A/C

Job Performance Q11
(n=9)

Chart: Bar graph with x-axis labeled 1 through 5, "Infrequently" below 1 and "Frequently" below 5. Y-axis from 0 to 9. Bars: 1 = 5, 2 = 5, 3 = 2, 4 = 1, 5 = 1.
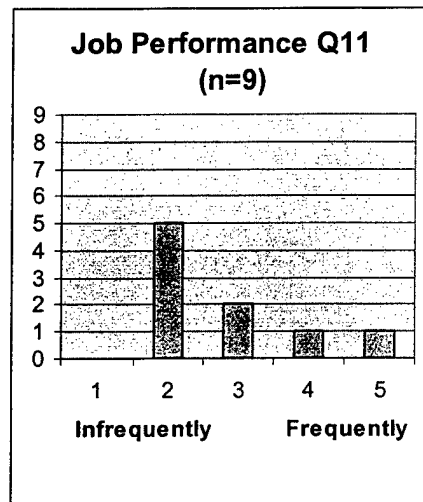
12. As compared with paper, information presented on the ITI-ALC system was
Engineers
Have to adjust to format

Job Performance Q12
(n=11)

Chart: Bar graph with x-axis labeled 1 (Easier), 2 (Harder), 3 (Same). Y-axis from 0 to 11. Bars: 1 = 5, 3 = 6.

ITI-ALC Hardware and Software Use

1. Carrying/wearing the ITI-ALC system while performing your task was
   Inspectors
   Not used to it
   Worried about banging it up. Would put it down before performing maintenance inspection

Usability Q1 (n=9)

A bar chart with vertical axis labeled 0 to 9 and horizontal axis labeled 1 through 5, with "Convenient" below 1 and "Inconvenient" below 4/5. Bar heights: 1 = 2, 2 = 3, 3 = 3, 4 = 1, 5 = 0.
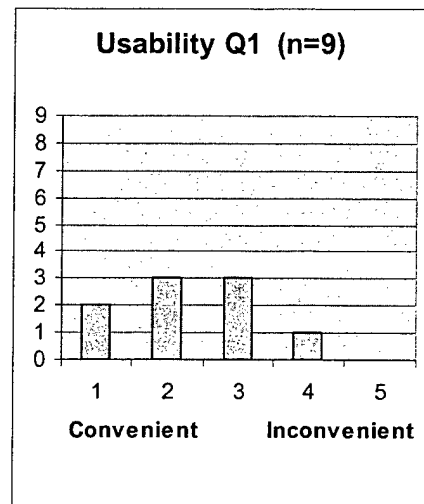
2. Was the system comfortable to wear?
   Mechanics
   Awkward

Usability Q2 (n=9)

A bar chart with vertical axis labeled 0 to 9 and horizontal axis labeled 1 and 2, with "Yes" below 1 and "No" below 2. Bar heights: 1 (Yes) = 8, 2 (No) = 1.
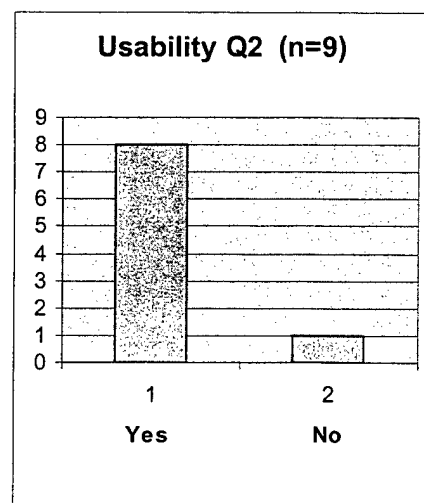
3. Did the straps fasten the ITI-ALC system securely to your body?
   Mechanics
   Had some trouble keeping it horizontal to the ground

Usability Q3 (n=9)

[Bar chart with y-axis 0-9. X-axis: 1 (Yes) bar at 7, 2 (No) bar at 2]
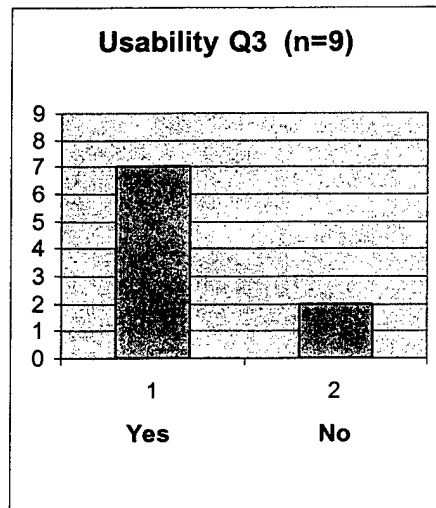
4. While using the computer to perform your task, the use of the pen was
   Inspectors
   Tapping was hard
   Mechanics
   Angle
   Getting hourglass to come up
   Tapping was problematic
   Tapping and touching caused problems
[With few exceptions, participants could not tap the screen and have the system consistently respond.]
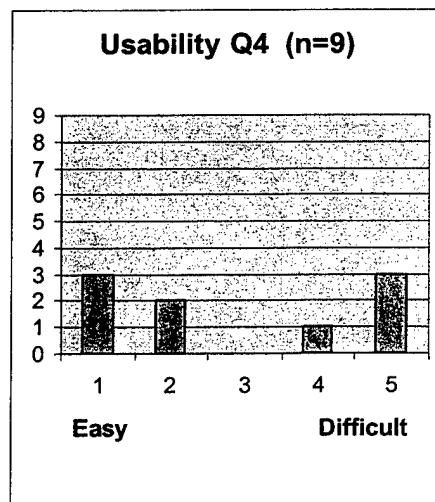
Usability Q4 (n=9)

[Bar chart with y-axis 0-9. X-axis: 1 (Easy) bar at 3, 2 bar at 2, 3 no bar, 4 bar at 1, 5 (Difficult) bar at 3]

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5. Was it obvious when the computer was busy working?

Usability Q5 (n=11)

[Bar chart: Y-axis 0 to 11. Category "1 Yes" = 10, Category "2 No" = 1]

1 — Yes   2 — No
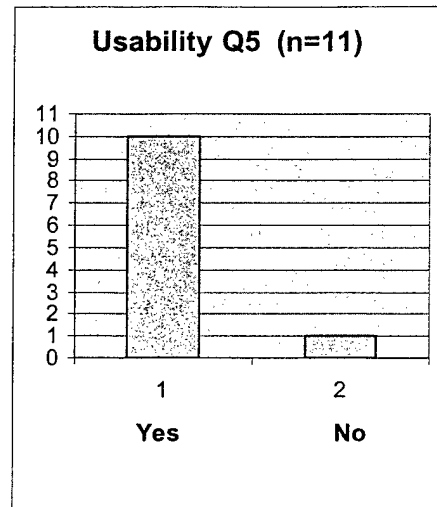
6. Information presented on the ITI-ALC system was
   Mechanics
   Better than before
   Engineers
   Some text was too small; however, if it were on a 17" monitor, it might be OK.

Usability Q6 (n=11)

[Bar chart: Y-axis 0 to 11. Category "1 Easy to read" = 7, Category "2" = 4, Categories 3, 4, 5 = 0]

Easy to read   Difficult to read
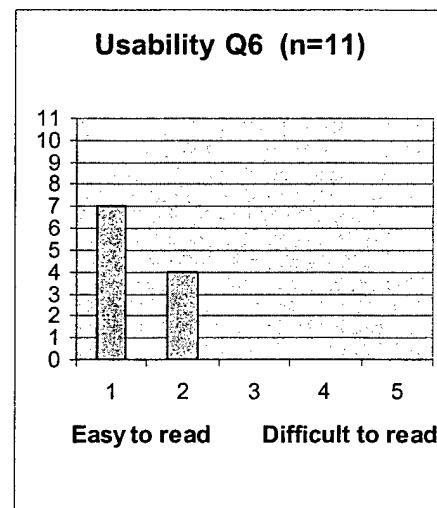
7. Information you entered into the ITI-ALC system was
   Engineers

Some text was too small; however, if it were on a 17" monitor, it might be OK.

Usability Q7 (n=11)

(bar chart: vertical axis labeled 0–11, horizontal axis labeled 1–5; bar at 1 reaches 9, bar at 2 reaches 2)

Easy to read   Difficult to read
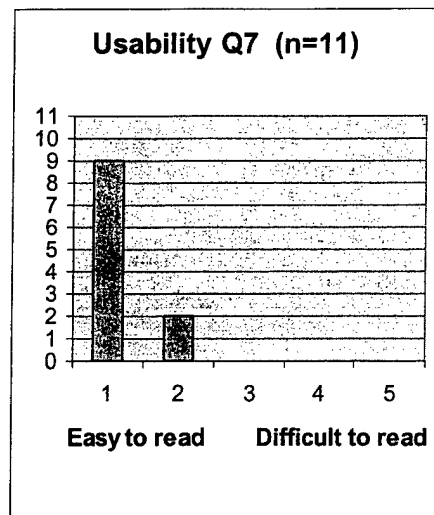
8. Information presented on the ITI-ALC system was
   <u>Mechanics</u>
   TOs only (inadequate)

Usability Q8 (n=11)

(bar chart: vertical axis labeled 0–11, horizontal axis labeled 1–5; bar at 1 reaches 5, bar at 2 reaches 5, bar at 5 reaches 1)

Adequate   Inadequate
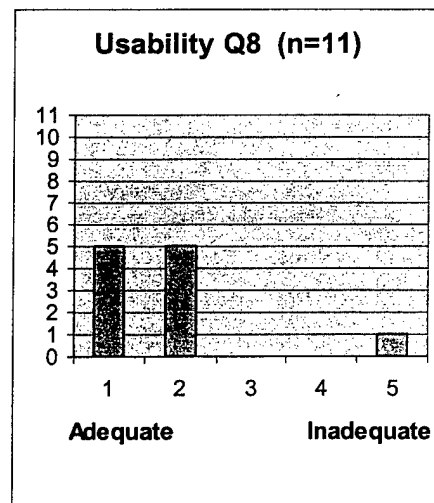
9. Entering text using the on-screen keyboard was
   <u>Inspectors</u>
   Pretty easy, but need to get used to handwriting
   <u>Mechanics</u>
   Better than March demonstration. Prefer to type information in with on-screen keyboard

Not too familiar with it

Usability Q9 (n=9)
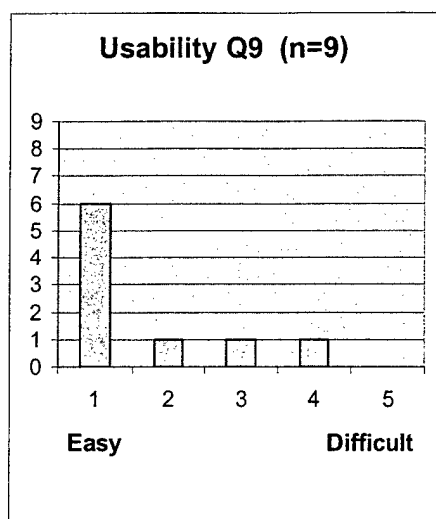
10. The meaning of the "stamp" icon was
    If it was not obvious, what would you suggest?

Usability Q10 (n=3)
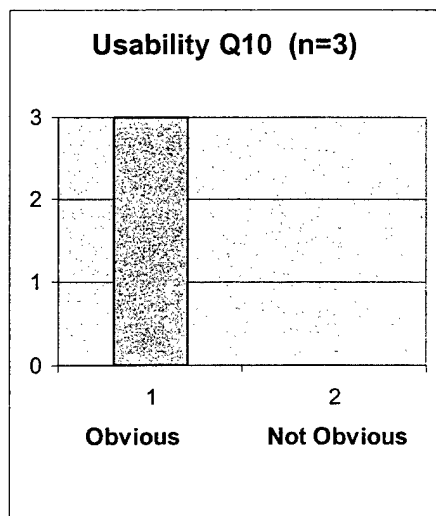
11. The meaning of the "envelope" icon was
    <u>Inspectors</u>
    Once I learn it
If it was not obvious, what would you suggest?
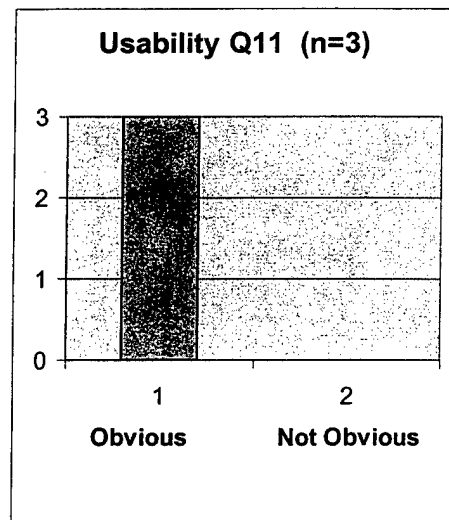
Usability Q11 (n=3)

3
2
1
0

1
Obvious

2
Not Obvious

12.   The navigation bar on the right side of the computer was

Usability Q12 (n=9)

9
8
7
6
5
4
3
2
1
0

1   2   3   4   5

Easy to understand   **Difficult**
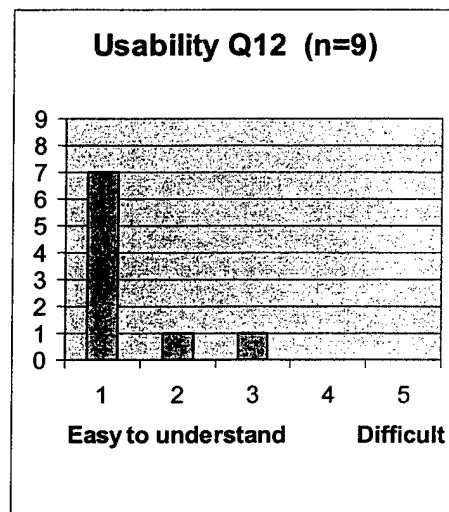
13.   Entering sketches on the ITI-ALC system was
         <u>Mechanics</u>
         Pen

Usability Q13 (n=8)
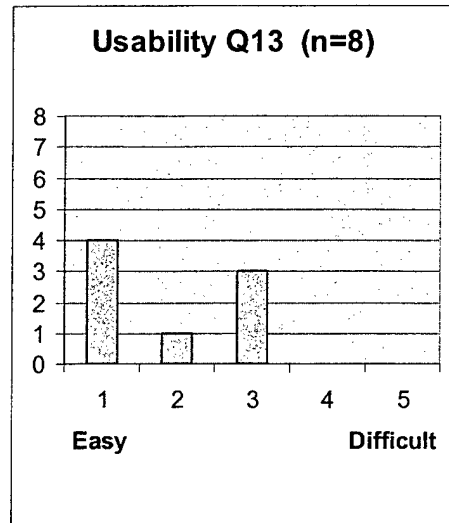
14. Using the camera to photograph the damaged area was
     Mechanics
     Hard to keep still
     Needs to be autofocus
     Real sensitive to height and focus. Focus was slow.
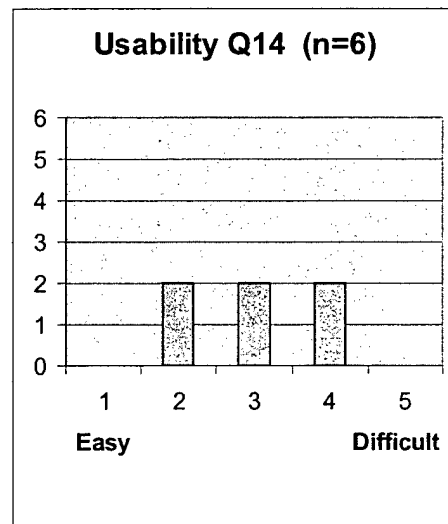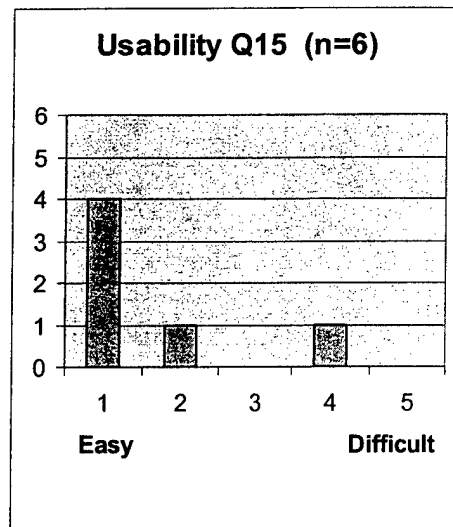
Usability Q14 (n=6)

15. Reviewing photos you had taken was

Usability Q15 (n=6)

16. Did you notice when photos were available for you to review

Usability Q16 (n=2)

17. Saving photos on the computer was

Usability Q17 (n=6)

18. Viewing photos was

Usability Q18 (n=8)
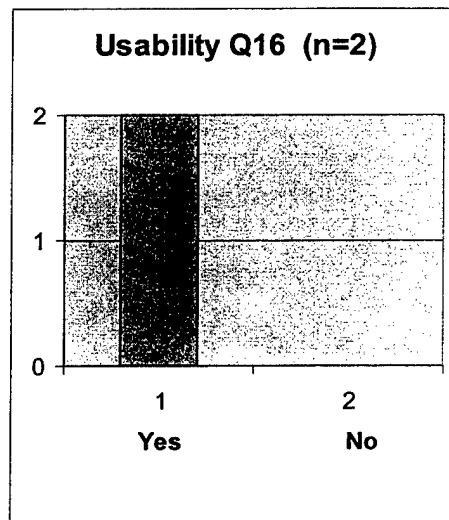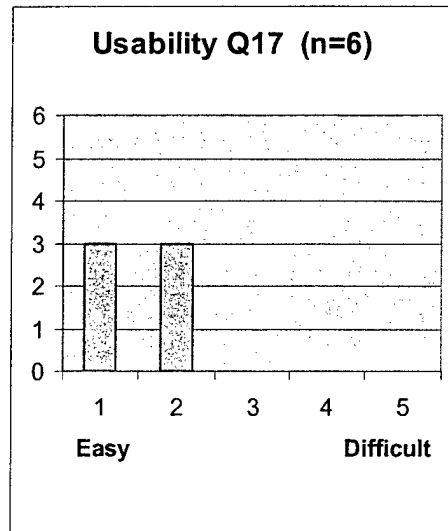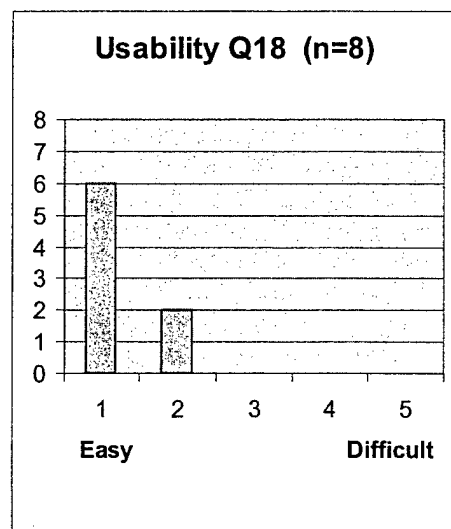
19. Recording voice notes was
     Mechanics
     Get somewhere quiet. Background noise was a problem. A lot of static, especially with mule running

Usability Q19 (n=8)

8	
7	
6	
5	
4	
3	
2	
1	
0	
	1 2 3 4 5
	Easy Difficult
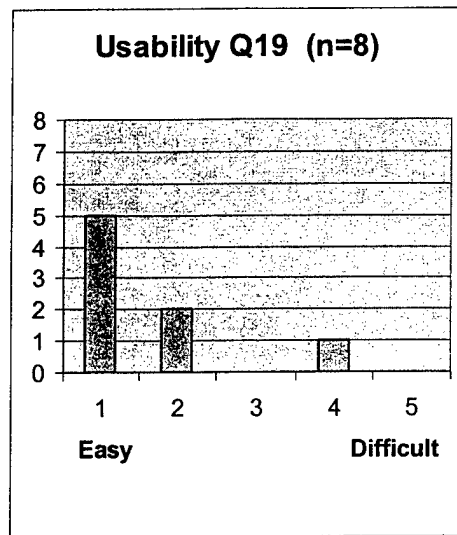
20. Playing back voice notes was
    <u>Mechanics</u>
    Had to hold up close to hear playback
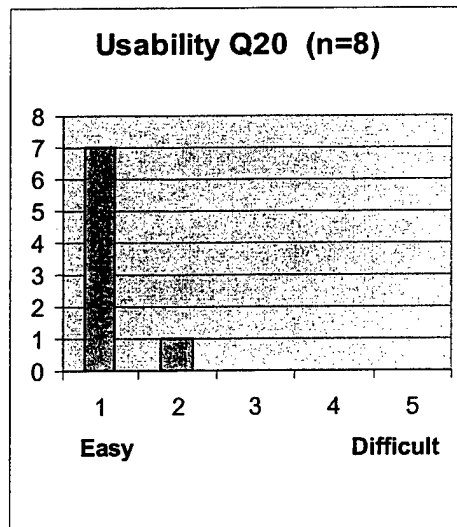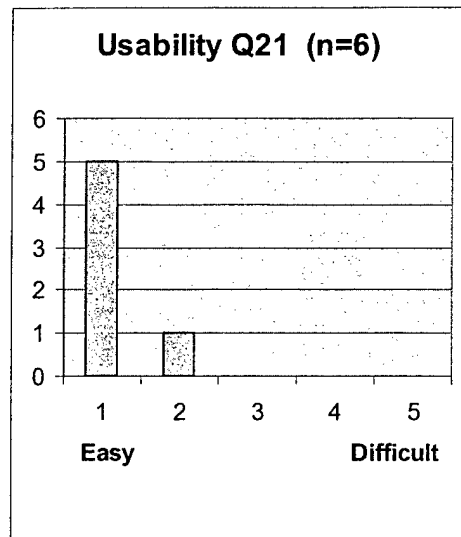
Usability Q20 (n=8)

8	
7	
6	
5	
4	
3	
2	
1	
0	
	1 2 3 4 5
	Easy Difficult

21. Reviewing voice notes you had recorded was

Usability Q21 (n=6)

(bar chart: x-axis labeled 1 "Easy" through 5 "Difficult", y-axis 0 to 6; bar at 1 ≈ 5, bar at 2 ≈ 1)

22.   Did you notice when voice notes were available for you to review

Usability Q22 (n=2)

(bar chart: x-axis labeled 1 "Yes", 2 "No", 3 "Maybe", y-axis 0 to 2; bar at 1 ≈ 2)
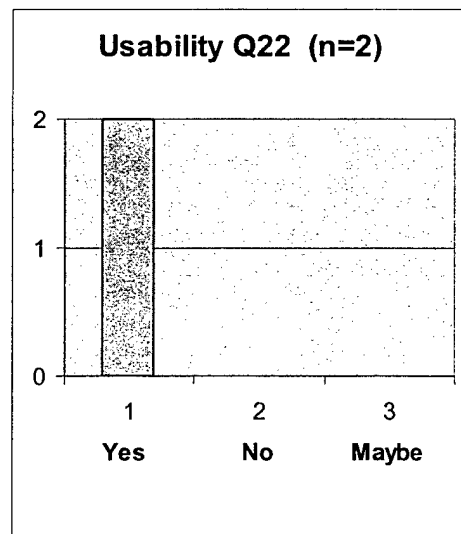
23.   Transmitting information for other people to read or approve was
       <u>Mechanics</u>
       Easy to send
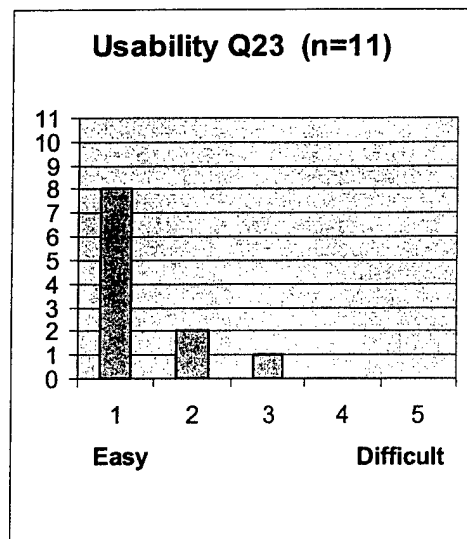
Usability Q23 (n=11)

Bar chart with y-axis from 0 to 11. X-axis labeled 1 (Easy) through 5 (Difficult). Bar at 1 = 8, bar at 2 = 2, bar at 3 = 1.

24.   Did you know when the computer was sending data?

Usability Q24 (n=11)

Bar chart with y-axis from 0 to 11. X-axis labeled 1 (Yes), 2 (No), 3 (Maybe). Bar at 1 = 10, bar at 2 = 1.

25.   The ITI-ALC system was

Usability Q25 (n=11)
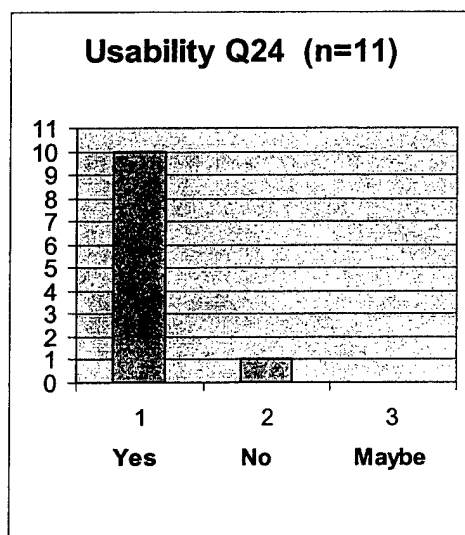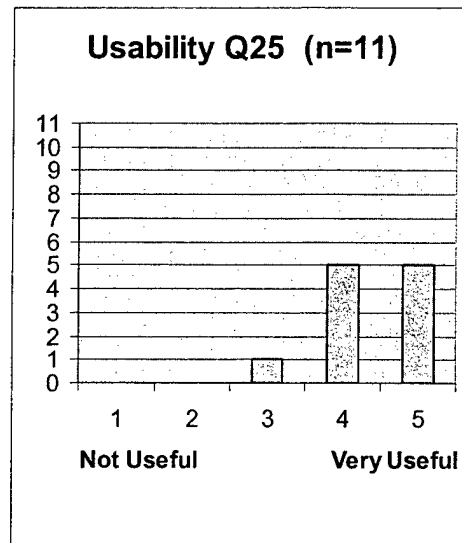
26. What did you like most about the ITI-ALC system
    <u>Inspectors</u>
    I-button
    Cuts out paperwork, saves time, more secure, All information needed at hand
    It's not heavy to hold while doing the job—older mechanics need more time working on this
system
    <u>Mechanics</u>
    Fairly simple to operate
    It makes 202's faster
    Faster and easier than paperwork
    Ease of filling out the 202s
    Was having hands on information at my finger tips, without having to leave the job.
    Not having to search through TO to find information
    <u>Engineers</u>
    Photo/voice information
    Complete and consolidated history of request

27. What did you like least about the ITI-ALC system
    <u>Inspectors</u>
    Pen
    It's not in use yet!!
    The glare on the face made it hard to see
    <u>Mechanics</u>
    Using the pen for tapping
    Taking pictures

The way you access different areas of the airplane for TO reference
Looking up information from the TOs. Too slow and too hard to go from page to page
When you pulled up a view of an area it didn't have the TO figure and index.
Not being familiar with its use
Engineers
Finding TO's
Nothing stands out

28.   Did you use an ITI-ALC system in a previous study?
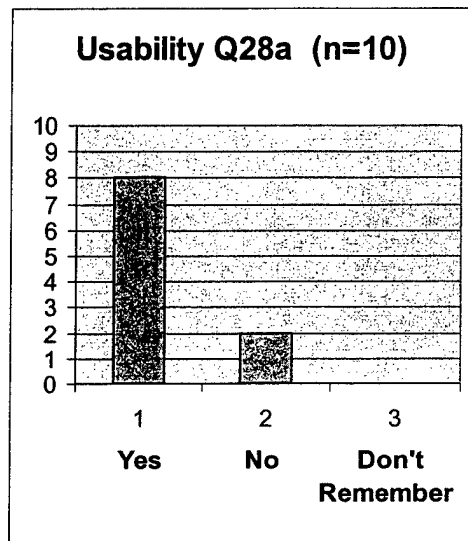
Usability Q28a (n=10)

If yes, which one (screen presentations primarily) did you prefer?

Usability Q28b (n=8)
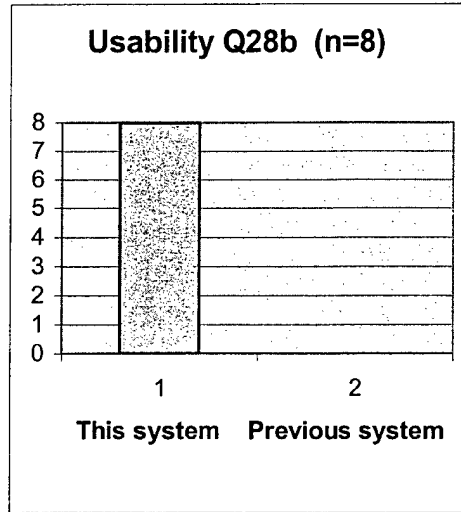
APPENDIX F

SCREEN WALKTHROUGHS

Appendix F: Screen Walkthroughs

ITI-ALC Screen Walkthrough - Inspectors

Login

User's manual is needed to show how to get to it.

[If the I-button was not removed after accessing the application, if frequently came loose and dropped on the floor]
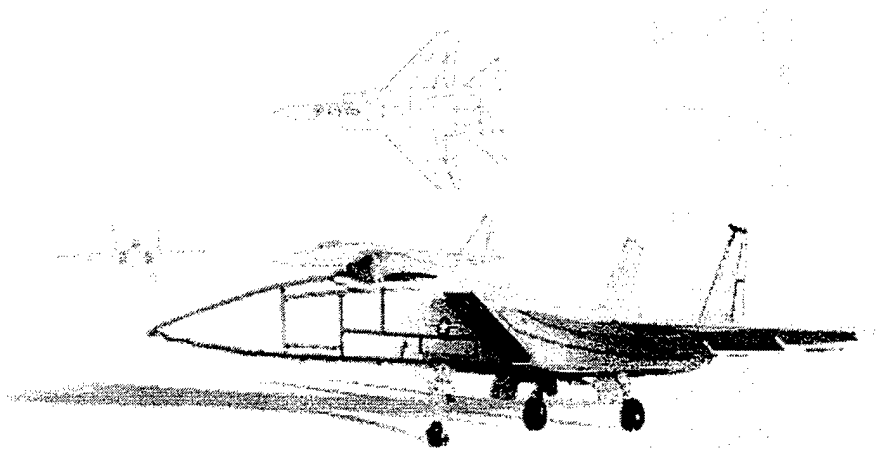
Please Insert Your Electronic Stamp Into The Receptor.

Select Aircraft

Pick area first. Cards in numerical sequence
Need to assure that planes on screen really represent what is on the floor especially for inspector.
Needs to be kept up to date. We can deep it up to date.

Select Aircraft

Dock 3		Dock 2	
7900073 07/20/98	7900074 07/21/98	7900075 07/22/98	7900076 07/23/98
7900077 07/24/98	8000053 08/03/98	8000054 08/04/98	8000055 08/05/98
8000056 08/06/98	8000057 08/07/98	8200054 08/16/98	8300055 08/17/98
8400056 08/18/98	8500073 08/19/98	8200053 08/13/98	8200052 08/12/98
8100051 08/11/98	8000059 08/10/98	8000058 08/09/98	8000052 07/31/98
8000051 07/30/98	8000050 07/29/98	7900079 07/28/98	7900078 07/27/98

Dock 4	Dock 1

DerekE

B
L   8
D   3
G

EXIT

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173 Task List
Pick area first. Cards in numerical sequence. Everything OK.

| 01 | 1A | 02 | 03 | 04 | 05 | 07 | 7A | 7B | 09 | 10 | 11 | 12 | 13 |

Hangar

173 List

173 SignOff

173 History

Tap an area number or scroll through this list to view work cards.
Tap the circle icon to the right of each task to select it.
To view the list of all checked task, tap the signoff icon.

AFMC 173 Task List	
01 - Forward Fuselage, Radome and Speed Brake	
12621	Visually inspect the left side load scissors for cracks, wear and corrosion. IAW 1F-15A/C/E-3-4.	✓
12622	Visually inspect the right side load scissors for cracks, wear and corrosion. IAW 1F-15A/C/E-3-4.	○
12643	Visually inspect radar antenna for hydraulic leaks, cracks, corrosion and any other defects. Defects will be annotated on AFLC Form 173.	✓
12657	Inspect radome hinge and radome hinge back up angle for warping, cracks, corrosion and missing fasteners IAW 1F-15A/E-6WC-6 and 1F-15A/C/E-3-1. (1200 hour inspection).	○
12660	Visually inspect upper and lower fuselage splice area, F.S. 415, for cracks and loose or damaged fasteners. Check skin for dents, cracks and buckles. (1200 hour inspection).	○
12666	Visually inspect the left and right diffuser ramp fixed hinge supports, using a mirror and flashlight, for cracks. Check the servocylinder for leakage, corrosion and cracks. (1200 hour inspection).	✓
12684	Visually inspect aileron rudder interconnect (ARI) for leakage. Inspect support bracket for cracks and scurity. Inspect electrical connectors for chaffing and	✓

Record Defects

Submit Defects

Defect History

T.O.

Help

EXIT

173 Sign-Off List
Sign off icon is like signing off that procedure. History tell what has been done

[Inspectors exhibited confusion between signing off using the E&I icon in the top left and the "SignOff" icon on the right side menu bar. Typically, they picked the "SignOff" icon instead of the E&I icon.]

User: ROBERTE   Tail Num: 8500073

01

Tap an area number or scroll through this list to review the checked tasks.
To add or remove a task from this list, return to the 173 list.
To complete the Sign Off for this list of tasks, plug in your electronic stamp and tap the stamp icon above.

AFMC 173 Sign Off List

01 - Forward Fuselage, Radome and Speed Brake	
12231	Visually inspect the left and right bypass air doors for obstsructions, distortion and cracks (Door 33 L/R). (1200 hour inspections.)
12305	Visually inspect A/C prior to disassembly for general condition to determine obvious discrepancies, deterioration (structure paint, flight controls, landing gear, etc) wear, tear and cleanliness.
12622	Visually inspect the right side load scissors for cracks, wear and corrosion. IAW 1F-15A/C/E-3-4.
12643	Visually inspect radar antenna for hydraulic leaks, cracks, corrosion and any other defects. Defects will be annotated on AFLC Form 173.

Hangar
173 List
173 SignOff
History
Record Defects
Submit Defects
Defect History
EXIT

173 History List
Need to list work category

User: DANEI		Tail Num: 7900073		
01 **06**				

Tap an area number or scroll through this list to review all Signed Off tasks for this aircraft.
You may tap an icon to the right to go to another screen or exit.

AFMC 173 History List			
01 – Forward Fuselage, Radome and Speed Brake			
12232	Visually inspect the left and right bypass air louvers and screens for obstructions, cracks and FOD. (1200 hour inspection.)	E&I Mechanic II	06/30/98 20:13:26
06 – Right Wing			
12207	Visually inspect the right wing-to-fuselage pins and bolts and the fuselage attach lugs for cracks. This satisfies IAT 16. Complete afto form 3 and submit to LFEFS. IAW 1F-15A-36.	E&I Mechanic II	06/30/98 20:13:26
12618	Visually inspect the right wing to fuselage attach pins at F.S. 509.5 thru 626.9, P/N 68A112177 and 68A112178, for corrosion, wear, galling, fretting or any other unsatisfactory condition. IAW 1F-15A-36.	E&I Mechanic II	06/30/98 20:13:26
12620	Visually inspect the right wing to fuselage attach bushings at F.S. 509.5 thru 626.9, P/N 68A112177 and 68A112178, for cracks, wear, galling, fretting or any other unsatisfactory condition. IAW 1F-15A-36.	E&I Mechanic II	06/30/98 20:13:26

Hangar
173 List
173 SignOff
173 History
Record Defects
Submit Defects
Defect History
T.O.
Help
EXIT

Standard Defect List

Looks good. Some need to be added to master.

Not used to using areas so didn't pick by area icon here. Record number for deficiencies column header, not obvious.

User: DEREKE   Tail Num 7900076

01 | 1A | 02 | 2A | 03 | 04 | 05 | 06 | 07 | 7A | 7B | 09 | 10 | 11 | 12

Tap an area number or scroll through this list to view the defects.
To Add or Change a defect, to submit tap the related copy icon.

New Defect

Blank Form

Standard Defect List

01 - Forward Fuselage, Radome and Speed Brake

1	FWD END OF HINGE CRACKED ON AIRCRAFT ABOVE DOOR 3L
14	MILD CORROSION ON DOOR OPEN LIMIT SWITCH, F.S. 460
15	MILD CORROSION ON DOOR CLOSED LIMIT SWITCH, F.S. 475
16	MILD CORROSION ON DOOR OPEN AND CLOSE LIMIT SWITCHES IN AIR REFUELING COMPARTMENT
2	FWD END OF HINGE CRACKED ON AIRCRAFT ABOVE DOOR 3R

Submit Defects List

Columns need labels

[Participants exhibited some difficulty remembering how to send the defect list (the envelope icon in the top left). In several instances they forgot to send it.]

[Navigation among several screens was problematic. Once this screen was completed, the system navigated back to the 173 Task List. This automatic navigation was "too far back" and confusing to the user.]

User: DANEI	Tail Num: 7900073
01	

Tap an area number or scroll through this list to review recorded defects.
Tap Submit, Hold, or Remove icon for each defect.
When all defects have been reviewed, tap the send icon above.

Submit Defects List		
01 – Forward Fuselage, Radome and Speed Brake		
95157	FWD END OF HINGE CRACKED ON AIRCRAFT ABOVE DOOR 3L, IAW 1F-15A-3-2	⊘ Submit ⊙ Hold ⊙ Remove
95160	FWD END OF HINGE CRACKED ON AIRCRAFT ABOVE DOOR 3L, IAW 1F-15A-3-2	⊘ Submit ⊙ Hold ⊙ Remove
95161	MILD CORROSION ON DOOR OPEN AND CLOSE LIMIT SWITCHES IN AIR REFUELING COMPARTMENT, IAW 1F-15A-32	⊘ Submit ⊙ Hold ⊙ Remove

Hangar
173 List
173 SignOff
173 History
Record Defects
Submit Defects
Defect History
T.O.
Help
EXIT

Defect History List
OK

02 | 2A

Tap an area number or scroll through this list to review all submitted defects for this aircraft.
You may tap an icon to the right to go to another screen or exit.

Defect History List

02 - Forward Cockpit

95146	MILD CORROSION IN COCKPIT ON FLOOR UNDER PILOT"S CONSOLE AND AROUND FASTENERS , IAW 1F-15A-23	E&I Mechanic II	06/30/98 18:40:13
95147	MILD CORROSION IN COCKPIT ON FLOOR UNDER PILOT"S CONSOLE AND AROUND FASTENERS , IAW 1F-15A-23	E&I Mechanic II	06/30/98 18:43:44

2A - Rear Cockpit or F-15 Equipment Computer

95148	ADFGKKKHTR, IAW 1F-15A/C/E-2-28GS-00-1	E&I Mechanic II	06/30/98 18:47:55

TO Selection
Going to take getting used to, but I like it

Search TOs By Document Title

A	B	C	D	E	F	G	H	I
L	M	N	O	P	Q	R	S	T	W

Search TOs By Category

- Acceptance and Functional Check Flight Procedures
- Aircraft Storage Manual
- Battle Damage Repair
- Checklist
- Corrosion Control (System Peculiar)
- Cross Servicing Guide
- Equipment Inventory List
- Fault Reporting
- Fault Isolation
- Flight Program Configurations
- General System
- General Vehicle
- Illustrated Parts Breakdown
- Inspection & Maintenance Requirements Manual
- Job Guide
- List of Applicable Publications
- Munitions Loading
- Nondestructive Inspection
- Nonnuclear Weapon Delivery Manual
- Schematic Diagram
- Structural Repair
- Weight Checklist and Loading Data
- Wiring Data
- Workcards
- Work Unit Code Manual

Help   EXIT

A

- ACCEPTANCE AND FUNCTIONAL CHECK FLIGHT PROCEDURES (1F-15E-6CF-1)
- ACCEPTANCE AND FUNCTIONAL CHECK FLIGHT (1F-15E-6CL-1)
- ACCESSORY GEARBOX SYSTEM -AIRFRAME MOUNTED ACCESSORY DRIVE S/S/SN 83-20-01 THRU 83-20-30 - JOB GUIDE (1F-15E-2-83JG-20-1)
- ACCESSORY GEARBOX SYSTEM -AIRFRAME MOUNTED ACCESSORY DRIVE S/S/SN 3-20-31 THRU END - JOB GUIDE (1F-15E-2-83JG-20-2)
- ACCESSORY GEARBOX SYSTEM -DRIVESHAFT - JOB GUIDE (1F-15E-2-83JG-10-1)
- ACCESSORY GEARBOX SYSTEM -GENERAL - JOB GUIDE (1F-15E-2-83JG-00-1)
- AEROSPACE GROUND EQUIPMENT - IPB (1F-15E-4-6)
- AIR CONDITIONING SYSTEM -DISTRIBUTION - JOB GUIDE (1F-15E-2-21JG-21-1)
- AIR CONDITIONING SYSTEM - FAULT ISOLATION (1F-15E-2-21FI-00-1)
- AIR CONDITIONING SYSTEM - GENERAL SYSTEM (1F-15E-2-21GS-00-1)
- AIR CONDITIONING SYSTEM -GENERAL - JOB GUIDE (1F-15E-2-21JG-00-1)
- AIR CONDITIONING SYSTEM -LIQUID COOLANT - JOB GUIDE (1F-15E-2-21JG-80-1)
- AIR CONDITIONING SYSTEM -PRESSURIZATION CONTROL -ANTI-G - JOB GUIDE (1F-15E-2-21JG-33-1)
- AIR CONDITIONING SYSTEM -PRESSURIZATION CONTROL - CABIN - JOB GUIDE (1F-15E-2-21JG-30-1)
- AIR CONDITIONING SYSTEM -PRESSURIZATION CONTROL -CANOPY SEAL - JOB GUIDE (1F-15E-2-21JG-31-1)
- AIR CONDITIONING SYSTEM -PRESSURIZATION CONTROL -WAVEGUIDES - JOB GUIDE (1F-15E-2-21JG-32-1)
- AIR CONDITIONING SYSTEM - SCHEMATIC DIAGRAM (1F-15E-2-21SD-00-1)
- AIR CONDITIONING SYSTEM -TEMPERATURE CONTROL - AIR CYCLE AIR CONDITIONING SYSTEM S/S/SN 21-64-01 THRU 21-64-21 - JOB GUIDE (1F-15E-2-21JG-64-1)
- AIR CONDITIONING SYSTEM -TEMPERATURE CONTROL -AIR CYCLE AIR CONDITIONING SYSTEM S/S/SN 21-64-22 THRU END - JOB GUIDE (1F-15E-2-21JG-64-2)
- AIR CONDITIONING SYSTEM -TEMPERATURE CONTROL -AVIONICS - JOB GUIDE (1F-15E-2-21JG-66-1)
- AIR CONDITIONING SYSTEM -TEMPERATURE CONTROL -BLEED AIR - JOB GUIDE (1F-15E-2-21JG-60-1)
- AIR CONDITIONING SYSTEM TEMPERATURE CONTROL - CABIN - JOB GUIDE (1F-15E-2-21JG-65-1)
- AIRCRAFT AND EQUIPMENT - LIST OF APPLICABLE PUBLICATIONS (1F-15A-01)
- AIRCRAFT BATTLE DAMAGE REPAIR (1F-15E-39)
- AIRCRAFT DESCRIPTION AND MAINTENANCE ORIENTATION - GENERAL VEHICLE (1F-15E-2-00GV-00-1)
- AIRCRAFT -ENGINE AND JFS OPERATION S/S/SN 05-20-01 THRU 05-20-07 - JOB GUIDE (1F-15E-2-05JG-20-1)
- AIRCRAFT -ENGINE AND JFS OPERATION S/S/SN 05-20-08 THRU END - JOB GUIDE (1F-15E-2-05JG-20-2)
- AIRCRAFT -GENERAL MAINTENANCE S/S/SN 05-00-01 THRU 05-00-11 - JOB GUIDE (1F-15E-2-05JG-00-1)
- AIRCRAFT -GENERAL MAINTENANCE S/S/SN 05-00-12 THRU 05-00-23 - JOB GUIDE (1F-15E-2-05JG-00-2)
- AIRCRAFT -GENERAL MAINTENANCE S/S/SN 05-00-24 THRU END - JOB GUIDE (1F-15E-2-05JG-00-3)
- AIRCRAFT -EMERGENCY PROCEDURES - JOB GUIDE (1F-15E-2-05JG-30-1)
- AIRCRAFT LAUNCH INSPECTION PROCEDURES - WORKCARDS (1F-15E-6WC-2-2)
- AIRCRAFT LEVELING - JOB GUIDE (1F-15E-2-08JG-00-1)

Defect Fill-In
Handwriting is alright. Needs to pick up writing a little better.
[Recording the defect by pressing the + icon was problematic. If the participant pressed "Submit Defects" icon from the right menu (a common mistake), a dialog box was presented. This dialog box was designed so that if it was accepted, the data entered on this form was lost, if the dialog was rejected the participant had a second chance to press the + icon. This screen interface (e.g., the + icon) was quite confusing and caused numerous errors along with unnecessary re-entry tasks due to the dialog]

User: DANEL   Tail Num. 7900073

Add or Change all information needed to complete this defect.
When the defect is complete, tap the "+" icon to record.

Area	01 - Forward Fuselage, Radome and Speed Brake
T.O. Number	1F-15A-3-2
Skill Code	AS - Aircraft Sheetmetal
Work Unit Code	11A000 - Forward Section
HOWMAL Code	190 - Cracked.
Description	FWD END OF HINGE CRACKED ON AIRCRAFT ABOVE DOOR 3L

TO 1F-15E-6

TECHNICAL MANUAL

INSPECTION AND MAINTENANCE
REQUIREMENTS MANUAL

USAF SERIES
F-15E AIRCRAFT

McDonnell Douglas Aerospace

F33657-86-C-2001
F33657-95-C-2007

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ITI-ALC Screen Walkthrough – Mechanics

Select Aircraft

Tail number is good. Output date is helpful.
Easy to understand
AFMC Form 202 Part A
Easier than our 202s. Indicators for picture and voice were small, but adequate

Select Aircraft

Dock 3			Dock 2	
7900073 07/20/98	7900074 07/21/98	7900075 07/22/98	7900076 07/23/98	B
7900077 07/24/98	8000053 08/03/98	8000054 08/04/98	8000055 08/05/98	L 8 D 3
8000056 08/06/98	8000057 08/07/98	8200054 08/16/98	8300055 08/17/98	G
8400056 08/18/98	8500073 08/19/98	8200053 08/13/98	8200052 08/12/98	
8100051 08/11/98	8000059 08/10/98	8000058 08/09/98	8000052 07/31/98	T.O.
8000051 07/30/98	8000050 07/29/98	7900079 07/28/98	7900078 07/27/98	Help
Dock 4			Dock 1	EXIT

Form 202 Part A
Pretty good
[Several participants tried to use the "T.O." icon on the right menu bar to fill-in the drop-down entitled "Tech Order."]

AFMC Form 202 Part A

Tap the parts icon to choose a part number from the aircraft drawing. Tap the sketch or sound buttons to add these features to your request. When Form 202 is complete, tap the send button to submit it to an engineer.

Part Number

Parts

Tech Order

| *************************** Select One *************************** | ▼ |

Work Stoppage | Yes ▼ | Organically Caused | No ▼ |

Deficiency & Recommendations

Send

TroyAS
7900073

Hangar

202a

202 Status

202 History

Keypad

T.O.

Help

EXIT

Thank You. Your AFMC…
Satisfied with that

↖Thank you. Your AFMC Form 202 A has been sent with the following
Control Number: 7900073-0087

To: Engineering

Date: 8/13/1998
Control Number: 7900073-0087

Initiator: Troy Gould
Office Symbol: LFEFS
Phone: 912-926-5407

Tail Number: 7900073

Part Number: 68A230173-2037

Location: Bldg. 300

Part Description: POD ASSY, Vertical stabilizer 2.00 diameter tip
NSN: 3333-000003

Air Logistic Specialist: Jan Felcan
Office Symbol: LFPB
Phone: 912-926-6030

TO/Dwg Number: 1F-15E-3-3

Work Stoppage: Yes
Organically Caused: No

Deficiency & Recommendations
MULTIPLE RIVETS MISSING ON LEFT
BOTTOM SIDE OF NOSE. REQUEST
ENGINEERING ASSISTANCE

**Tap the Start button to fill out a new AFMC Form 202 Part A
for Tail Number: 7900073**

Start

OR

Below is a list of all form 202's you have submitted

Fuselage station could be used to help identify/differentiate between 202s. Noun would be good column to help differentiate among 202s

Fine

Below is a list of all the Form 202's you have submitted and their current status.

Tap the view button to see the details of a Form 202

Control Number	Part Number	Date	Status	View AFMC Form 202
7900073-0048	68A230174-2005	08/05/98	Complete	View
7900073-0049	HT4057-3-6A	08/05/98	Complete	View
7900073-0050	HT4057-3-6A	08/05/98	Complete	View
7900073-0052	SDF SD	08/05/98	Complete	View
7900073-0053	SD SD SD	08/05/98	Assigned to Gaylord Oyler	View
7900073-0054	DSF FDH G H	08/05/98	Work in Progress (Gaylord Oyler)	View
7900073-0055	68A230173-2037	08/06/98	Complete	View
7900073-0058	68A230191-2005	08/06/98	Complete	View
7900073-0060	SDF SD	08/11/98	In Scheduling	View
7900073-0077	HT4057-3-6A	08/11/98	In Scheduling	View
7900073-0087	68A230173-2037	08/13/98	In Scheduling	View
7900073-0102	68A230191-2005	08/13/98	In Scheduling	View

TroyAS 7900073

Hangar

202A

202 Status

202 History

T.O.

Help

EXIT
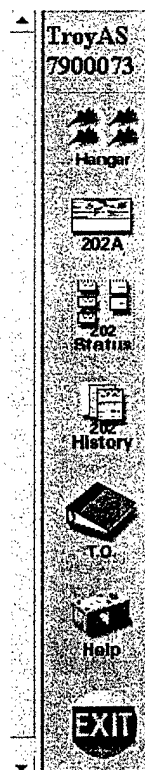
Part number selection

Good pictures. Large. Like index picking

May need to point to an area, rather than the reference designator. In case ref des does not refer to area damaged.

Pretty easy to do. Point to part and number comes up. Didn't show all part #'s. Need to show all.

TO and Figure with this picture. This is a lot of help right here. TO figure and index is needed for ordering part
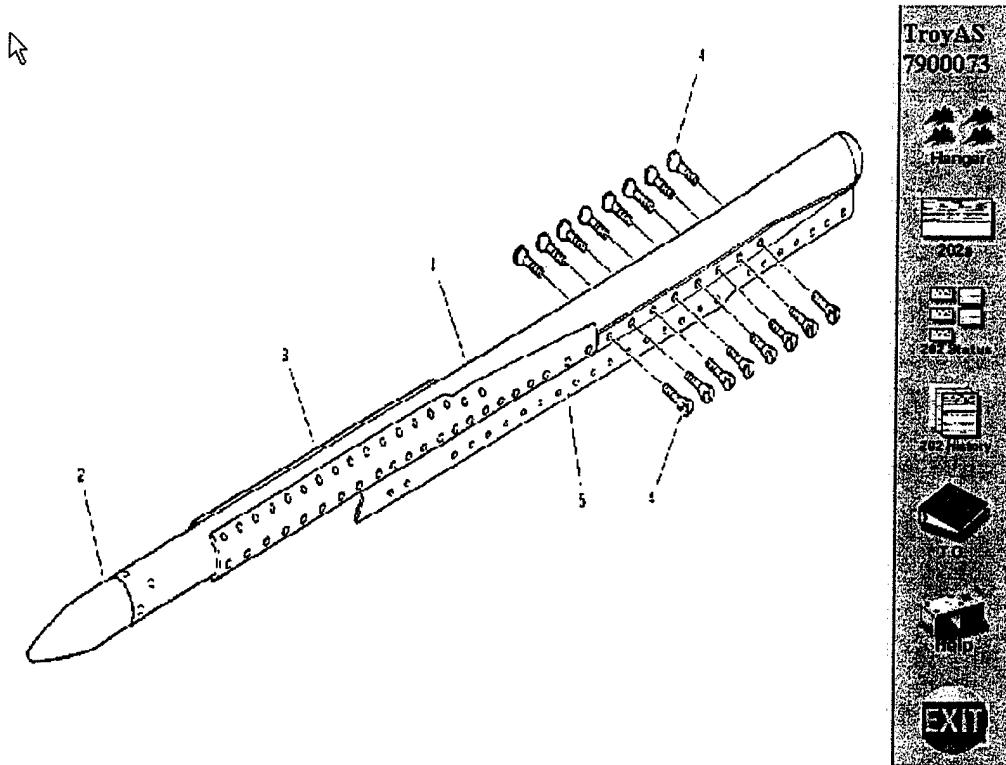
Below is a list of all the Form 202's that have been completed for this aircraft.
Tap the view button to see the Details of a Form 202

Control Number	Initiator	Part Number	Date	View AFMC Form 202
7900073-0007	AS Mechanic I	68A230174-2005	08/04/98	View
7900073-0048	Troy Gould	68A230174-2005	08/05/98	View
7900073-0049	Troy Gould	HT4057-3-6A	08/05/98	View
7900073-0050	Troy Gould	HT4057-3-6A	08/05/98	View
7900073-0052	Troy Gould	SDF SD	08/05/98	View
7900073-0055	Troy Gould	68A230173-2037	08/06/98	View
7900073-0058	Troy Gould	68A230191-2005	08/06/98	View

Hanger

202A

202 Status

202 History

T.O.

Help

EXIT

Sketch tool
Like picking different colors to sketch.
Pretty good
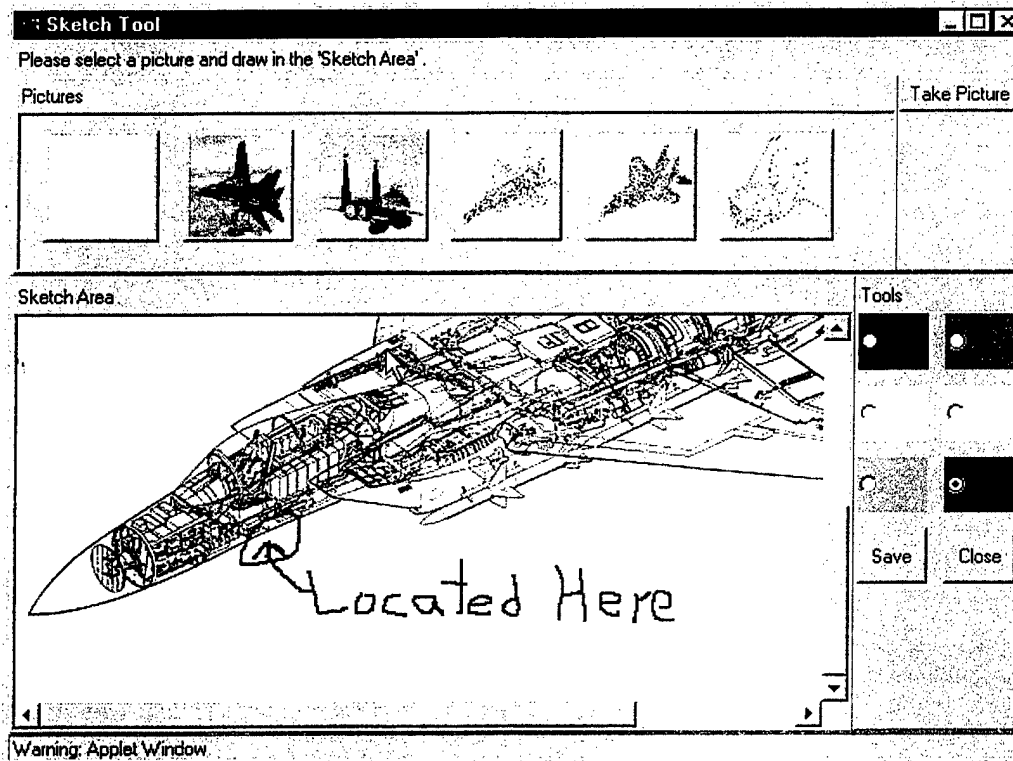
Record Sound Note
Send/Close
Easiest part
Easy to use
When record not a good idea to do it out there (on the floor). More static than anything else.

AFMC Form 202 Part A

Tap the parts icon to choose a part number from the aircraft drawing. Tap the sketch or sound buttons to add these features to your request. When Form 202 is complete, tap the send button to submit it to an engineer.

TroyAS
7900073

Hangar

202A

202 Status

202 History

T.O.

Help

EXIT

Record Sound Note ✕

Part Number

Record Sound   Stop Recording

Tech Order

1F-15E-3-3 Door:

Work Stoppage

Play Sound

Deficiency & Recc

Close

Sound!

Send

305

202 History helpful on what else has been written up

AFMC Form 202

After reviewing the Form 202 data below, you may tap an icon to the right to go to another screen or exit.

7900073

Part A	**Part B**
To Engineer: Engineering	To Initiator: AS Mechanic I
	From Engineer/ES: Engineering
Initiator: AS Mechanic I	Date:
Office Symbol: LFPB	
Phone: 912-926-6030	Disposition Instructions:
Location: Bldg. 83	
	Repair Instructions
Date: 08/12/98	
Control Number: 7900073-0083	Recissions Completion of S/N:
Tail Number: 7900073	Recissions Date:
Air Logistic Specialist: Jan Felcan	Requires AFMC Form 252:
Office Symbol: LFPB	Requires AF Form 2600:
Phone: 912-926-6030	
	AFTO Form 95/DD Form 1574 Entry

202A

202 Status

History

TOI

Help

EXIT

TO Selection

Would like to pick TOs based on physical location on aircraft. Provide only information/TOs relevant to the specialty of the technician

Search TOs By Document Title

A	B	C	D	E	F	G	H	I
L	M	N	O	P	Q	R	S	T	W

A

- ACCEPTANCE AND FUNCTIONAL CHECK FLIGHT PROCEDURES (1F-15E-6CF-1)
- ACCEPTANCE AND FUNCTIONAL CHECK FLIGHT (1F-15E-6CL-1)
- ACCESSORY GEARBOX SYSTEM -AIRFRAME MOUNTED ACCESSORY DRIVE S/S/SN 83-20-01 THRU 83-20-30 - JOB GUIDE (1F-15E-2-83JG-20-1)
- ACCESSORY GEARBOX SYSTEM -AIRFRAME MOUNTED ACCESSORY DRIVE S/S/SN 3-20-31 THRU END - JOB GUIDE (1F-15E-2-83JG-20-2)
- ACCESSORY GEARBOX SYSTEM -DRIVESHAFT - JOB GUIDE (1F-15E-2-83JG-10-1)
- ACCESSORY GEARBOX SYSTEM -GENERAL - JOB GUIDE (1F-15E-2-83JG-00-1)
- AEROSPACE GROUND EQUIPMENT - IPB (1F-15E-4-6)
- AIR CONDITIONING SYSTEM -DISTRIBUTION - JOB GUIDE (1F-15E-2-21JG-21-1)
- AIR CONDITIONING SYSTEM - FAULT ISOLATION (1F-15E-2-21FI-00-1)
- AIR CONDITIONING SYSTEM - GENERAL SYSTEM (1F-15E-2-21GS-00-1)
- AIR CONDITIONING SYSTEM -GENERAL - JOB GUIDE (1F-15E-2-21JG-00-1)
- AIR CONDITIONING SYSTEM -LIQUID COOLANT - JOB GUIDE (1F-15E-2-21JG-80-1)
- AIR CONDITIONING SYSTEM -PRESSURIZATION CONTROL -ANTI-G - JOB GUIDE (1F-15E-2-21JG-33-1)
- AIR CONDITIONING SYSTEM -PRESSURIZATION CONTROL - CABIN - JOB GUIDE (1F-15E-2-21JG-30-1)
- AIR CONDITIONING SYSTEM -PRESSURIZATION CONTROL -CANOPY SEAL - JOB GUIDE (1F-15E-2-21JG-31-1)
- AIR CONDITIONING SYSTEM -PRESSURIZATION CONTROL -WAVEGUIDES - JOB GUIDE (1F-15E-2-21JG-32-1)
- AIR CONDITIONING SYSTEM - SCHEMATIC DIAGRAM (1F-15E-2-21SD-00-1)
- AIR CONDITIONING SYSTEM -TEMPERATURE CONTROL - AIR CYCLE AIR CONDITIONING SYSTEM S/S/SN 21-64-01 THRU 21-64-21 - JOB GUIDE (1F-15E-2-21JG-64-1)
- AIR CONDITIONING SYSTEM -TEMPERATURE CONTROL -AIR CYCLE AIR CONDITIONING SYSTEM S/S/SN 21-64-22 THRU END - JOB GUIDE (1F-15E-2-21JG-64-2)
- AIR CONDITIONING SYSTEM -TEMPERATURE CONTROL -AVIONICS - JOB GUIDE (1F-15E-2-21JG-66-1)
- AIR CONDITIONING SYSTEM -TEMPERATURE CONTROL -BLEED AIR - JOB GUIDE (1F-15E-2-21JG-60-1)
- AIR CONDITIONING SYSTEM TEMPERATURE CONTROL - CABIN - JOB GUIDE (1F-15E-2-21JG-65-1)
- AIRCRAFT AND EQUIPMENT - LIST OF APPLICABLE PUBLICATIONS (1F-15A-01)
- AIRCRAFT BATTLE DAMAGE REPAIR (1F-15E-39)
- AIRCRAFT DESCRIPTION AND MAINTENANCE ORIENTATION - GENERAL VEHICLE (1F-15E-2-00GV-00-1)
- AIRCRAFT -ENGINE AND JFS OPERATION S/S/SN 05-20-01 THRU 05-20-07 - JOB GUIDE (1F-15E-2-05JG-20-1)
- AIRCRAFT -ENGINE AND JFS OPERATION S/S/SN 05-20-08 THRU END - JOB GUIDE (1F-15E-2-05JG-20-2)
- AIRCRAFT -GENERAL MAINTENANCE S/S/SN 05-00-01 THRU 05-00-11 - JOB GUIDE (1F-15E-2-05JG-00-1)
- AIRCRAFT -GENERAL MAINTENANCE S/S/SN 05-00-12 THRU 05-00-23 - JOB GUIDE (1F-15E-2-05JG-00-2)
- AIRCRAFT -GENERAL MAINTENANCE S/S/SN 05-00-24 THRU END - JOB GUIDE (1F-15E-2-05JG-00-3)
- AIRCRAFT -EMERGENCY PROCEDURES - JOB GUIDE (1F-15E-2-05JG-30-1)
- AIRCRAFT LAUNCH INSPECTION PROCEDURES - WORKCARDS (1F-15E-6WC-2-2)
- AIRCRAFT LEVELING - JOB GUIDE (1F-15E-2-08JG-00-1)

Search TOs By Category

- Acceptance and Functional Check Flight Procedures
- Aircraft Storage Manual
- Battle Damage Repair
- Checklist
- Corrosion Control (System Peculiar)
- Cross Servicing Guide
- Equipment Inventory List
- Fault Reporting
- Fault Isolation
- Flight Program Configurations
- General System
- General Vehicle
- Illustrated Parts Breakdown
- Inspection & Maintenance Requirements Manual
- Job Guide
- List of Applicable Publications
- Munitions Loading
- Nondestructive Inspection
- Nonnuclear Weapon Delivery Manual
- Schematic Diagram
- Structural Repair
- Weight Checklist and Loading Data
- Wiring Data
- Workcards
- Work Unit Code Manual

Help   EXIT

Viewing TOs

Liked being able to enlarge size. Should be able to search TOs by TO #. Sheet metal Tech Data only.

Very good, no problem

TO 1F-15E-3-4

TECHNICAL MANUAL

STRUCTURAL REPAIR
ORGANIZATIONAL AND INTERMEDIATE

CONTROL SURFACES AND REMOVABLE
STRUCTURAL COMPONENTS

USAF SERIES
F-15E
AIRCRAFT

McDonnell Douglas Aerospace

F33657-86-C-2001
F33657-92-C-2102 F33657-95-C-2007

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Battle damage repair information is provided in TO 1F-15E-3-7.

This publication supersedes TO 1F-15E-3-4 dated 1 November 1989 changes 1 through 16 and

Take Picture
Good if it's general, but if magnification is required... If need a scribe then not enough for area.
Liked being able to send pictures
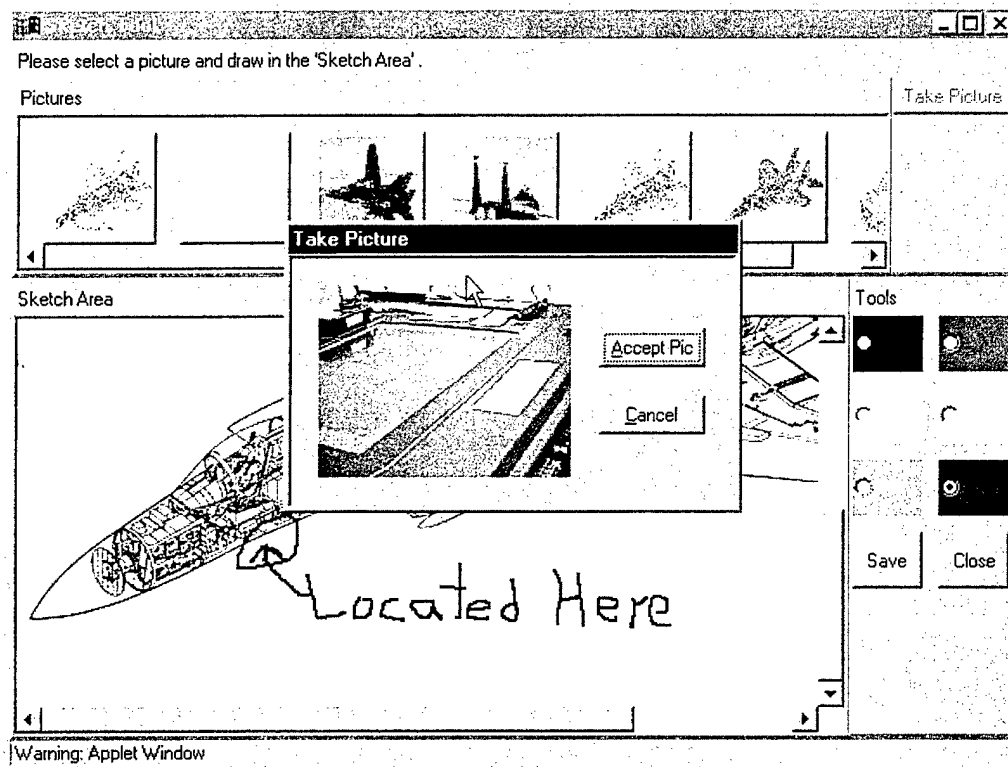
ITI-ALC Screen Walkthrough - Engineers

Assign
   Should be able to open the first one and continue on through all of the new ones and assign them without going back to main screen.

SCREEN NOT SHOWN

Form 202B
   Highlight the deficiency and recommendation. Visually enhance these because refer to it most. Did engineer answer the entire request? How was the answer?

AFMC Form 202 A

To: GOyler	Control Number: 8000055-0203	Work Stoppage: Y
	Tail Number: 8000055	Organically Caused: N
Initiator: AS Mechanic III	Part Number: HT4057-3-6A	
Department: LFPB	Part Description: SCREW, Close tolerance (73197)	Deficiency/Recommendations: THIS IS A TEST
Phone: 912-926-6030	NSN: 3333-000009	

User
GOyler

202b

202 History

T.O.

Help

Recissions Completion Of S/N   ◯ Yes ⦿ No

Requires AF Form 252?   ◯ Yes ⦿ No

Requires AF Form 2600?   ◯ Yes ⦿ No

AFTO Form/DD Form 1574 Entry

Submit

EXIT

202 Selection
Submit is an unusual word choice. "Open" might be better word choice.

AFMC Form 202 Selection Screen

To fill out AFMC Form 202 Part B for a particular item, click the Submit button.

Control Number	Username	Date	Part Number	AFMC Form 202
7900073-0053	Troy Gould	08/05/98	SD SD SD	Submit
7900073-0054	Troy Gould	08/05/98	DSF FDH G H	Submit
7900073-0061	AS Mechanic I	08/06/98	68A230191-2005	Submit
7900073-0064	AS Mechanic I	08/06/98	68A230173-2037	Submit
7900073-0065	AS Mechanic I	08/06/98	68A230191-2005	Submit

GOyler

202b

202 History

T.O

Help

EXIT

History
No problem

Select a Tail Number to View Its History of AFMC Form 202

AFCT SERIAL NO	OUTPUT DATE	View AFMC Form 202's
7900073	07/20/98	Goto History
7900074	07/21/98	Goto History
7900075	07/22/98	Goto History
7900076	07/23/98	Goto History
7900077	07/24/98	Goto History
7900078	07/27/98	Goto History
7900079	07/28/98	Goto History
8000050	07/29/98	Goto History
8000051	07/30/98	Goto History
8000052	07/31/98	Goto History
8000053	08/03/98	Goto History
8000054	08/04/98	Goto History
8000055	08/05/98	Goto History
8000056	08/06/98	Goto History
8000057	08/07/98	Goto History
8000058	08/09/98	Goto History
8000059	08/10/98	Goto History
8100051	08/11/98	Goto History
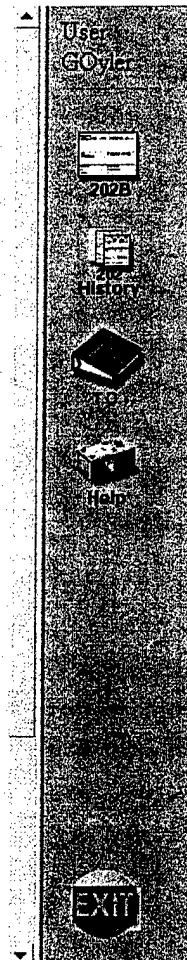
TO Selection

We would look at the number first. Search by/organized by number.

A

- ACCEPTANCE AND FUNCTIONAL CHECK FLIGHT PROCEDURES (1F-15E-6CF-1)
- ACCEPTANCE AND FUNCTIONAL CHECK FLIGHT (1F-15E-6CL-1)
- ACCESSORY GEARBOX SYSTEM -AIRFRAME MOUNTED ACCESSORY DRIVE S/S/SN 83-20-01 THRU 83-20-30 - JOB GUIDE (1F-15E-2-83JG-20-1)
- ACCESSORY GEARBOX SYSTEM -AIRFRAME MOUNTED ACCESSORY DRIVE S/S/SN 3-20-31 THRU END - JOB GUIDE (1F-15E-2-83JG-20-2)
- ACCESSORY GEARBOX SYSTEM -DRIVESHAFT - JOB GUIDE (1F-15E-2-83JG-10-1)
- ACCESSORY GEARBOX SYSTEM -GENERAL - JOB GUIDE (1F-15E-2-83JG-00-1)
- AEROSPACE GROUND EQUIPMENT - IPB (1F-15E-4-6)
- AIR CONDITIONING SYSTEM -DISTRIBUTION - JOB GUIDE (1F-15E-2-21JG-21-1)
- AIR CONDITIONING SYSTEM - FAULT ISOLATION (1F-15E-2-21FI-00-1)
- AIR CONDITIONING SYSTEM - GENERAL SYSTEM (1F-15E-2-21GS-00-1)
- AIR CONDITIONING SYSTEM -GENERAL - JOB GUIDE (1F-15E-2-21JG-00-1)
- AIR CONDITIONING SYSTEM -LIQUID COOLANT - JOB GUIDE (1F-15E-2-21JG-80-1)
- AIR CONDITIONING SYSTEM -PRESSURIZATION CONTROL -ANTI-G - JOB GUIDE (1F-15E-2-21JG-33-1)
- AIR CONDITIONING SYSTEM -PRESSURIZATION CONTROL - CABIN - JOB GUIDE (1F-15E-2-21JG-30-1)
- AIR CONDITIONING SYSTEM -PRESSURIZATION CONTROL -CANOPY SEAL - JOB GUIDE (1F-15E-2-21JG-31-1)
- AIR CONDITIONING SYSTEM -PRESSURIZATION CONTROL -WAVEGUIDES - JOB GUIDE (1F-15E-2-21JG-32-1)
- AIR CONDITIONING SYSTEM - SCHEMATIC DIAGRAM (1F-15E-2-21SD-00-1)
- AIR CONDITIONING SYSTEM -TEMPERATURE CONTROL - AIR CYCLE AIR CONDITIONING SYSTEM S/S/SN 21-64-01 THRU 21-64-21 - JOB GUIDE (1F-15E-2-21JG-64-1)
- AIR CONDITIONING SYSTEM -TEMPERATURE CONTROL -AIR CYCLE AIR CONDITIONING SYSTEM S/S/SN 21-64-22 THRU END - JOB GUIDE (1F-15E-2-21JG-64-2)
- AIR CONDITIONING SYSTEM -TEMPERATURE CONTROL -AVIONICS - JOB GUIDE (1F-15E-2-21JG-66-1)
- AIR CONDITIONING SYSTEM -TEMPERATURE CONTROL -BLEED AIR - JOB GUIDE (1F-15E-2-21JG-60-1)
- AIR CONDITIONING SYSTEM TEMPERATURE CONTROL - CABIN - JOB GUIDE (1F-15E-2-21JG-65-1)
- AIRCRAFT AND EQUIPMENT - LIST OF APPLICABLE PUBLICATIONS (1F-15A-01)
- AIRCRAFT BATTLE DAMAGE REPAIR (1F-15E-39)
- AIRCRAFT DESCRIPTION AND MAINTENANCE ORIENTATION - GENERAL VEHICLE (1F-15E-2-00GV-00-1)
- AIRCRAFT -ENGINE AND JFS OPERATION S/S/SN 05-20-01 THRU 05-20-07 - JOB GUIDE (1F-15E-2-05JG-20-1)
- AIRCRAFT -ENGINE AND JFS OPERATION S/S/SN 05-20-08 THRU END - JOB GUIDE (1F-15E-2-05JG-20-2)
- AIRCRAFT -GENERAL MAINTENANCE S/S/SN 05-00-01 THRU 05-00-11 - JOB GUIDE (1F-15E-2-05JG-00-1)
- AIRCRAFT -GENERAL MAINTENANCE S/S/SN 05-00-12 THRU 05-00-23 - JOB GUIDE (1F-15E-2-05JG-00-2)
- AIRCRAFT -GENERAL MAINTENANCE S/S/SN 05-00-24 THRU END - JOB GUIDE (1F-15E-2-05JG-00-3)
- AIRCRAFT -EMERGENCY PROCEDURES - JOB GUIDE (1F-15E-2-05JG-30-1)
- AIRCRAFT LAUNCH INSPECTION PROCEDURES - WORKCARDS (1F-15E-6WC-2-2)
- AIRCRAFT LEVELING - JOB GUIDE (1F-15E-2-09JG-00-1)

Sketch tool
      To be able to pick from other photos. Attach from other places.